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URLIM - A UNIFIED RADOME LIMITATIONS COMPUTER PROGRAM. VOLUME 2--ETC(U)

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Technical Memorandum

URLIM—A UNIFIED RADOME LIMITATIONS COMPUTER PROGRAM, VOLUME 2—USER'S GUIDE

R. K. FRAZER

THE JOHNS HOPKINS UNIVERSITY ■ APPLIED PHYSICS LABORATORY

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URLIM, a unified radome limitations computer program, has been developed to aid the radome design engineer by providing a definition of the maximum flight performance capabilities of radome materials. URLIM numerically determines the response of the radome to aerodynamic heating and loading. It computes the following as functions of trajectory time: thermal stress; radar boresight error rates; missile-radome attachment stresses caused by maneuvers, pressure, and drag forces; and the onset of radome melting. The basic output of the program is a notation of trajectory time at which the radome reaches its design limitations. Many options are available to the user of the URLIM program that provide a wide variety of analysis capability. For this reason, URLIM may also be considered as a general purpose aerodynamic heat transfer program as well as a specific purpose radome limitations program. Volume 1 of this report presents the theoretical background of the analysis techniques used in URLIM; Volume 2 provides a detailed explanation of how to use URLIM.

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ABSTRACT

URLIM, a unified radome limitations computer program has been developed to aid the radome design engineer by providing a definition of the maximum flight performance capabilities of radome materials. URLIM numerically determines the response of the radome to aerodynamic heating and loading. It computes the following as functions of trajectory time: thermal stress; radar boresight error slopes; missile-radome attachment stresses caused by maneuvers, pressure, and drag forces; and the onset of melting. The basic output of the program is a notation of trajectory time at which the radome reaches its design limitations. Many options are available to the user of the URLIM program that provide a wide variety of analysis capability. For this reason URLIM may also be considered as a general purpose aerodynamic heat transfer program as well as a specific purpose radome limitations program. Volume 1 of this report presents the theoretical background of the analysis techniques used in URLIM; Volume 2 provides a detailed explanation of how to use URLIM.

PREFACE

The purpose of this volume is to provide a detailed explanation of how to use the URLIM program. Also included herein is a discussion of the general objectives of the URLIM program itself (i.e., what physical conditions it can simulate and what its essential outputs are). This later discussion provides an overview of the information required by the program so that the specific data descriptions can be understood in their proper context. Also embodied in this volume (specifically in the Appendixes) is a description of the complete subroutine library that complements the URLIM program. These routines comprise the Standard Heat Transfer Program (SHTP) library and are documented herein for reference.

CONTENTS

ILLUSTRATIONS

1. BACKGROUND AND INTRODUCTION

The Unified Radome Limitations Computer Program (URLIM) has been developed to improve significantly the accuracy and speed with which a radome designer may define the permissible operating regime of a supersonic missile. Moreover, the program may have greater utility as a preliminary systems design tool by affording the ability to rapidly assess a candidate radome material's usefulness for high speed flight. A secondary aspect of the program, but one that is no less useful, is that the structure being analyzed need not be a radome but may be any body subjected to transient heating. The program contains numerous options that are user-selectable and that provide a means of controlling the amount and type of analysis performed.

Before a detailed discussion of the use of the URLIM program is presented, a general discussion of radome limitations will be given. The discussion will include a definition of the data requirements for URLIM.

The flights of current and proposed tactical missiles through the atmosphere occur at relatively high speeds so that the target seeker equipment requires a radome to protect it from aerodynamic heating and wind loading. Also, the radome provides aerodynamic fairing to reduce drag. Consequently, radomes used on missiles must satisfy a number of criteria to be successful. First, they must be dielectric materials, (i.e. transparent to radar frequency electromagnetic (EM) radiation). Second, they must be streamlined, so as to offer low aerodynamic drag. Third, they must be able to withstand the environment created by the high speed flight of the missile through the atmosphere.

In order to satisfy these three basic design criteria the radome designer: (1) selects a plastic or ceramic material of suitable thickness, (2) shapes it aerodynamically, and (3) attempts to define how fast and how far the material will fly before it no longer satisfies the first two criteria. This latter aspect of a radome design is seen to be a definition of the radome's flight limitations and is a complicated analysis task for the following reasons: (1) the aerodynamic heating and loading environment must be defined reliably,

(2) the effects on radar transmission must be determined, and (3) the response of the material to transient heating must be calculated. To be more specific, a radome limitations analysis must examine the thermal and mechanical response of the radome over all possible trajectories commensurate with the missile's propulsion capabilities. A flight limit would then be presented as plots of all of these trajectories with the failure points marked on each trajectory. Since there are many combinations of trajectory parameters, it must be decided how to "plot" a trajectory and how to select a reasonable number of parameters.

Trajectories have three basic aspects: a velocity history, an altitude history, and a downrange history (we assume no cross-range components in the trajectory with no loss of generality). The flight regime of a missile may generally be depicted as an area in an altitude-versus-range plot (an elevation view of the flight space). Such a picture is sketched in Fig. 1a. The figure shows several flight paths for various launch angles and ceiling altitudes. For each one of these flight paths, a variety of velocity histories could be used depending on the propulsion system used by the missile and other considerations. Figure 1b shows some typical velocity history possibilities. To complete the description Fig. 1c shows the altitude histories that would result from the trajectories sketched. To describe the flight potential of a missile, it would suffice to evaluate each of the velocity histories over each of the flight paths. In order to show the flight limitations of the missile radome, a dot is placed on each velocity history and on the appropriate position in the altitude-range plot. The velocity history plot (Fig. 1b) has five such dots plotted and the dashed line plotted through the dots approximates the locus of all failure points on all similar velocity histories. There are also five dots plotted on the altitude-range figure that depict the flight limitations. In this way different flight paths are flown with several velocity histories, and in each case a velocity limit plot is made. Corresponding points on the altitude-range plot can also be drawn. Combining these data will then give a "plot" of the particular radome's limitations in the atmosphere. For any particular radome material, as different wall thicknesses, or different launch angles, or different flight path shapes (e.g. line-of-sight versus boost-cruise) are used the resulting velocity limits may

a. Hypothetical mission profiles

b. Variety of velocity histories possible for one profile

c. Corresponding altitude history for each velocity history

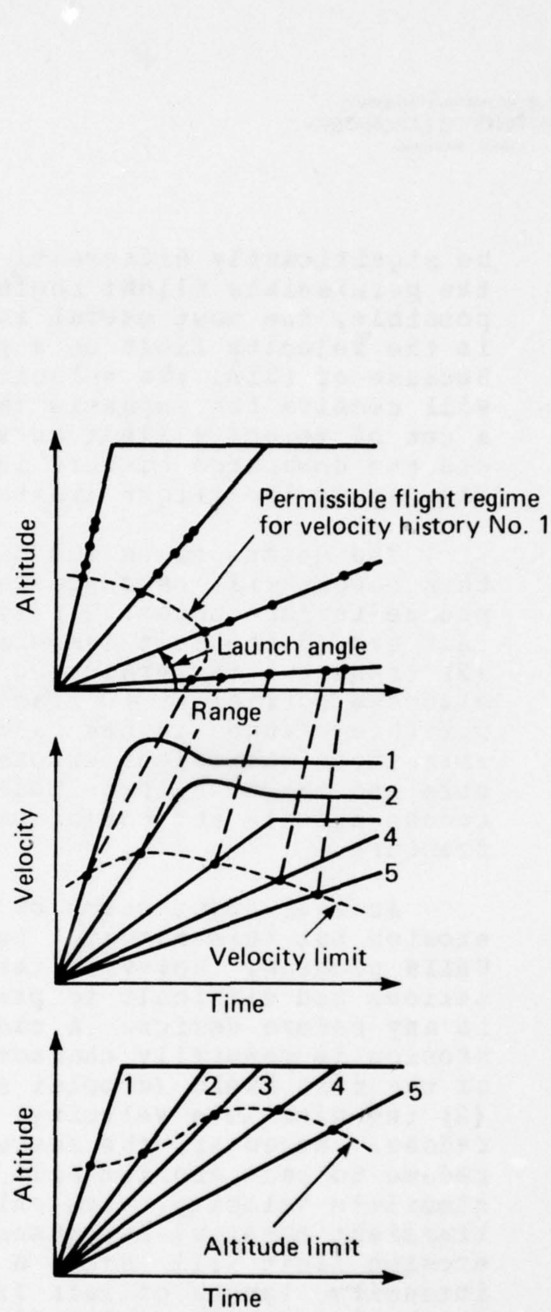


Fig. 1 General Radome Limits Plotting Techniques

be significantly different. While it is helpful to know the permissible flight regime in as many aspects as possible, the most useful information for radome design is the velocity limit on a particular flight path. Because of this, the velocity limit curve (c.f. Fig. 1b) will receive the emphasis throughout this report. With a set of velocity limit curves for several flight paths and the downrange history information, the other ways of displaying the flight limits can be generated easily.

The descriptions and discussions that follow in this report will be concerned with the following four radome failure modes: (1) temperatures in the radome that exceed the melt temperature of the radome material, (2) transient temperature gradients that cause thermal stresses sufficient to fracture the radome, (3) temperature changes in the radome wall that cause radar aberations (boresight errors), and (4) aerodynamic pressure and maneuver loads that cause stresses at the radome-missile attachment point sufficient to cause fracture.

Another major cause of radome failure is rain erosion but this material response is not covered by the URLIM program. However, the problem of rain erosion is serious and difficult to predict and must be considered in any radome design. A radome's response to rain erosion is generally characterized by: (1) the severity of the rain field (droplet size and number/unit volume), (2) the missile's velocity, and (3) the shape of the radome. Moreover, the susceptibility of any given radome to rain erosion will depend primarily on the missile's velocity, with only secondary dependence on transient material responses. In other words, a rain erosion limit will state a combination of rain field intensity, length of rain field, and velocity beyond which the missile cannot fly.

The four limits of melting, thermal stress, aerodynamic load, and boresight error are secondary effects that result from the transient thermal response of the radome and as such are very trajectory-dependent. For example, an alumina radome flown on a trajectory with low acceleration could eventually fly at a very high speed so long as the transient thermal gradients were low and severe thermal stresses were not developed. Conversely, an alumina radome flown at a high acceleration will fail due to thermal shock quite early in the

flight. In summary, the secondary material responses are highly dependent on trajectory parameters and must be evaluated via trajectory simulation to determine their attendant flight limits.

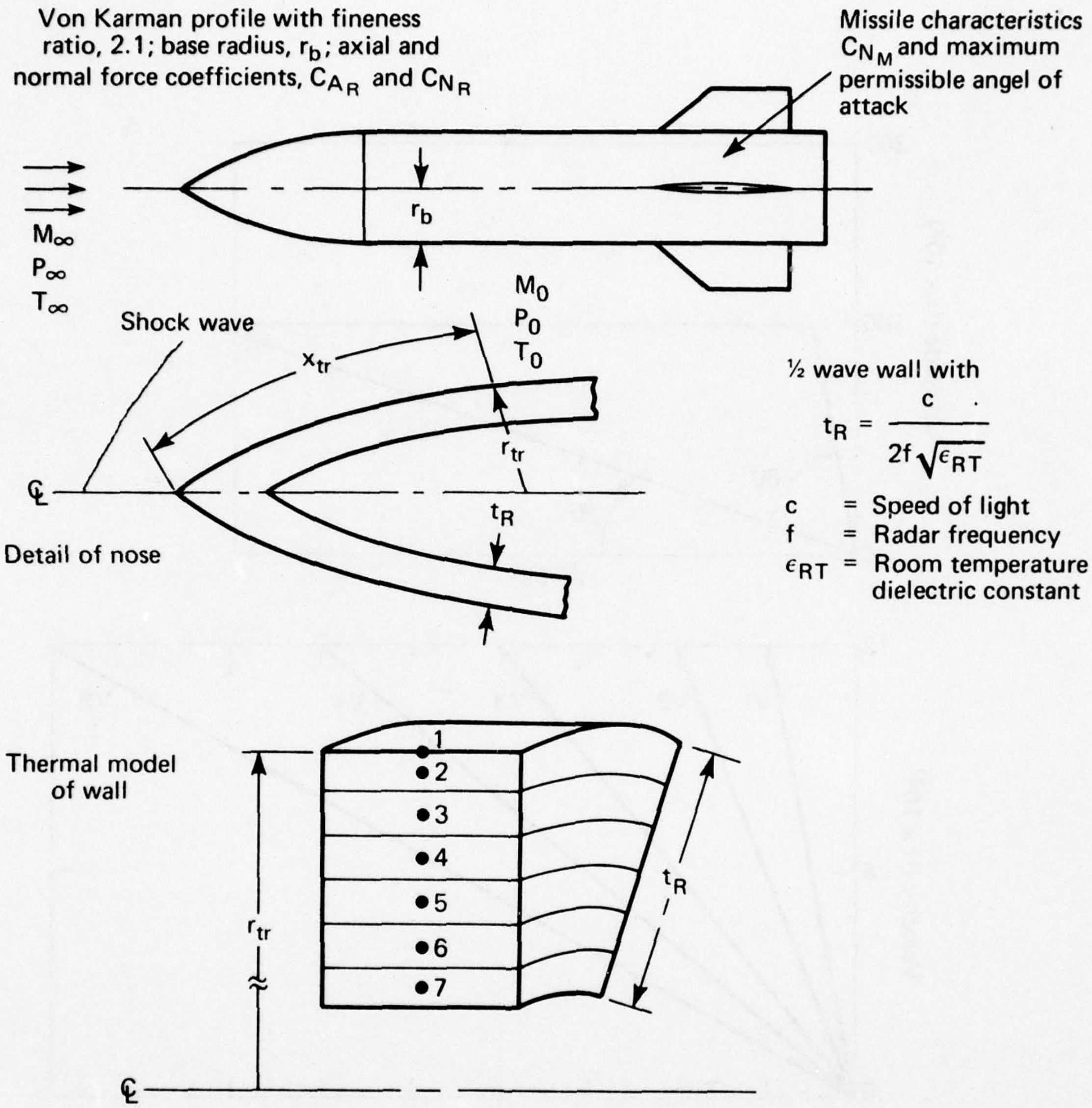
The example cited above of the alumina radome with different flight limits on different trajectories points out an interesting source of confusion with regard to thermal stresses. An appropriately selected set of trajectories can produce one set of flight limits while a different set of trajectories over the same range of velocities and altitudes can produce another set of limits. This ambiguity is possible because thermal stresses arise from temperature gradients and simply raising a radome's temperature uniformly (or with moderate difference) will not produce appreciable stresses. Therefore, it is not inconceivable that a set of trajectories could be tailored for any given material wherein thermal stresses would never be a limit. It is also possible that, for some materials, these trajectories might not be too useful for a tactical missile. It will suffice here only to mention these "stress-free" trajectories and note that the URLIM pogram will accept any velocity history as input. A series of analyses could be run with URLIM to discover the stress failure free paths, if desired. From this discussion we conclude that, when thermal stress is the overall limiting factor, the definition of a flight limit for a radome design will not be unique. Moreover, the region of uncertainty should be explored by the URLIM user.

In order to use URLIM to perform a limit analysis, the user must establish a model of the radome flight. As will become clear, this is not always an easy task because each of the four limiting factors mentioned above require considerable basic input data, and the URLIM user may spend considerable effort in gathering these required data. The first item that should be determined is the description of the structure to be modeled. Previous work (Ref. 1) has indicated that the position on a radome where the aerodynamic flow changes from laminar to turbulent is the most severe from a heat transfer standpoint. Therefore, this station on the particular radome of interest should be modeled for calculations of boresight error, melting, and thermal stress. It is generally permissible to perform only a one-dimensional heat transfer analysis at this transition point, but a two- or three-dimensional analysis

can be done if desired. In general, a multidimensional analysis will significantly increase the amount of input required and has been shown to offer a *negligible* increase in accuracy (c.f. Ref. 1, Sections 3 and 4). The heat transfer analysis section of URLIM requires that the structure being analyzed be divided into lumped masses or nodes, within which temperatures will be considered constant at any specific time. For the sake of accuracy, the radome wall thickness at the transition point should therefore be divided into several small nodes. However, as the size of the nodes is decreased, the amount of time required by URLIM for the trajectory simulation increases so that a compromise must be reached between accuracy and program execution time. Volume 1 of this report provides information on how to calculate an appropriate node size.

To complete the description of the radome, the thermal transport and mechanical properties of the radome material must be provided. These properties include thermal conductivity, specific heat, infrared emissivity, Young's modulus, Poisson's ratio, and free thermal expansion. Whenever possible these properties should be given as functions of temperature up to the melting point of the material.

Figure 2a is a sketch of the radome geometry selected in the sample problem that is discussed throughout this report. The figure shows the specific data that were mentioned generally above. The figure shows the general missile geometry, the specific location on the radome for the limit analysis, and the material properties that are required. All of the data shown in this figure must be determined before URLIM is run; i.e., these data are part of the required input. The radome wall is shown divided into six thermal nodes with a seventh node of zero volume at the exterior surface. This zero-volume (or surface) node is a requirement of the aerodynamic heating calculations. As will be described in detail later, the definition of the thermal interconnections between the nodes can be accomplished by using standard geometries or by manual input of the conduction paths. The details of this data entry will be explained later. Figure 2c shows some of the detail required in specifying the geometry of the thermal models. The models shown in this figure are for the sample case described throughout this report.



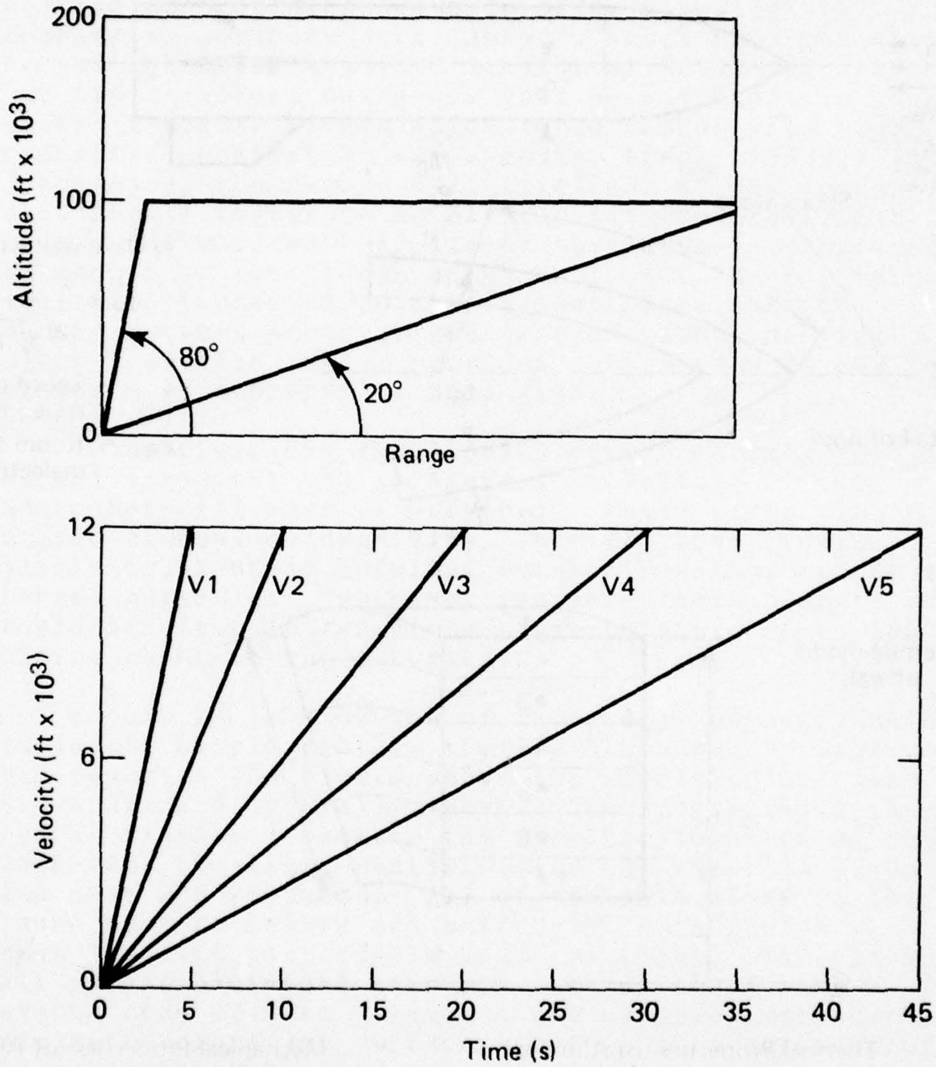
Thermal Properties (of Alumina)

Temp (°R)	ρc_p	k	ϵ_T	ϵ_D
460	45.9	23.0	0.78	9.6
860	59.5	11.8	0.76	9.8
1260	67.0	7.0	0.70	10.0
2060	76.2	3.7	0.52	10.5
3260	86.9	3.6	0.36	11.4
4060	97.3	4.6	0.29	12.3

Mechanical Properties (of Alumina)

Temp (°f)	Modulus	ν	$\Delta L/L$
0	50×10^6	0.28	0.0
1200	47.8×10^6	0.28	4.8×10^{-3}
2400	38×10^6	0.30	11.4×10^{-3}
2800	30×10^6	0.30	13.8×10^{-3}
3200	18×10^6	0.30	16.2×10^{-3}
3600	0	0.30	18.6×10^{-3}

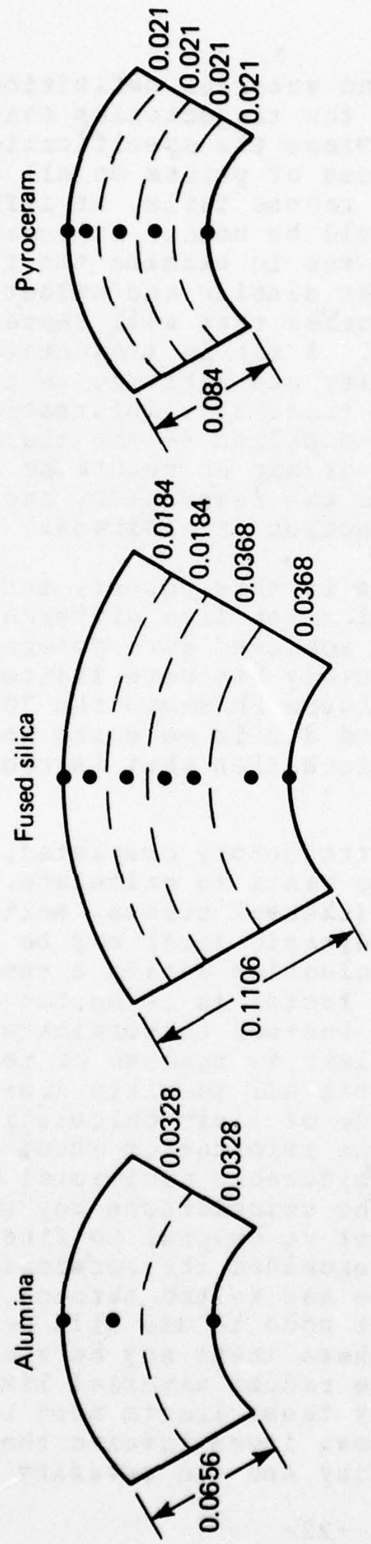
Fig. 2a Sketch of Some Required Information for an URLIM Run



Tabular data required:

1. Air properties versus temperature and pressure
2. Atmosphere model, i.e., pressure and temperature versus altitude

Fig. 2b Example of Trajectory Data Required for an URLIM Run



Notes:
- All dimensions in inches
- All models have outer radius of 0.86184 in.
- Dotted lines indicate divisions for thermal stress
- Dots indicate thermal node locations

Fig. 2c URLIM Geometry Definitions for Sample Problem

After the geometry and material definitions of the radome have been decided, the trajectories that will be used must be specified. Since the specification of the velocity limits is the locus of points on all possible trajectories at which the radome fails, an infinite number of trajectories could be used. It remains, therefore, for the URLIM user to examine the flight potential of the particular missile and select a manageable number of trajectories that will represent the range of possible flights. A single trajectory specification requires the velocity and altitude as a function of time. To complete the trajectory information two additional tables must be supplied -- the thermal and mass transport properties of air as functions of temperature and pressure, and the temperature and pressure of the atmosphere as a function of altitude.

In the sample problem in this report, two line-of-sight trajectories were flown at five different accelerations. The altitudes achieved were governed by the launch angle of the trajectory but were limited to a maximum of 100 000 ft. Figure 2b shows the 10 different trajectories that were used and in so doing indicates the type of trajectory information that is required by URLIM.

With the radome and trajectory completed, the user must decide what limits he wants to calculate. The limits mentioned earlier (thermal stress, melting, boresight error, and aerodynamic load) may be selected in any combination for evaluation during a run. Also, if more than one limiting factor is being run at one time, the user may select whether to terminate the simulation when any one limit is reached or to continue through the trajectory until all possible limits have been met. This latter mode of limit calculation will provide all of the possible information about the radome material but may take considerable additional computer time to execute. Also, the calculations may be meaningless; that is, it would not be helpful to find out that the boresight error rate exceeded its permissible level some time after the radome had melted through. Moreover, deciding which limit mode to use will depend on several items. Some of these items may be known a priori; e.g., how well the radome material limitations are known and how strictly these limits must be adhered to. Other less easily known items involve the interactions of material capability and the severity of the

selected trajectory. In general the decision between the "complete limit analysis" mode and the "lowest limit" mode will be made through experience.

The general procedures outlined above are what must be followed to generate a radome material limits plot. Other types of aerodynamic analyses can be performed by URLIM because the program has been designed with considerable flexibility. That is, the general analysis capabilities of URLIM can be selected in combinations to perform any of a variety of tasks. For example, the very simple problem of determining the one-dimensional transient response of a structure with one boundary exposed to an independently specified heat flux can be easily modeled wth URLIM. If the structure is a cylinder, then it would be possible to have the thermal stresses associated with the particular heat flux calaculated and, if desired, plotted in history form by a CalComp plotter. On the other end of the spectrum of capabilities for URLIM, it is possible to do more than one limit calculation at one time. As many as nine materials can be evaluated over any number of trajectories and the resulting limits plotted in any number of combinations. In practice, it has been observed that the limitations in URLIM's use lie in the ability of the user to formulate the problem rather than in limitations of capacity within the program. This general capability of URLIM must be carefully considered by the user; i.e., is it better to try to solve a large limits problem with one run of URLIM or break the problem down into smaller units that are run one at a time? This question of how to apply URLIM's capability will be answered through experience.

In the section that follows the required inputs to URLIM will be described. Within this section the organization of the basic analysis units of URLIM will be shown along with the essential data flow paths. This will be accomplished via a general block diagram of the URLIM program. Following this introductory description will be a specific card-by-card discussion of the required input.

2. PROGRAM ORGANIZATION

The URLIM program can simulate missile flights through the atmosphere and in doing so requires a considerable amount of basic input data. Figure 3 depicts the overall internal structure of the URLIM program and shows many of its essential data flows. At the top of the figure is the section that deals with the reading in of the required data. The first group of required data is that which defines the thermal transport properties and dielectric constant of the radome material. Since the URLIM program is, at its most basic level, a transient thermal response program, the thermal properties of the material are essential. In order to calculate thermal stresses the mechanical properties of the material are required and are shown as the next block of required data.

Since a flight through the atmosphere is being simulated, the thermal and mass transport properties of air must be available. The third block at the top of Fig. 3 represents the reading in of these data, which are assumed to be functions of temperature and pressure. The next block of data completes the description of the atmosphere by tabulating the temperature, pressure, and speed of sound as functions of altitude. The next block of data provides the means for calculating the local aerodynamic conditions that exist at the precise location of interest on the radome by tabulating the pressure ratio, Mach ratio, and velocity gradient term (for stagnation points only) as functions of freestream Mach number. The following block shows the input of some of the aerodynamic characteristics of the radome and missile. These values are required by the aerodynamic load routine so that maneuver and pressure forces on the radome may be calculated and, in turn, the attachment area stresses can be evaluated. The last block of input data on the top line of Fig. 3 provides for specifying the trajectory in terms of altitude and velocity versus time. In this block of data, there may be other time-dependent parameters that would be required by the particular run of URLIM. Examples of such inputs are shown in the form of externally supplied temperatures

DEFINITION OF SYMBOLS

α	Angle of attack of missile
α_{max}	Maximum permissible angle of attack
A	Velocity gradient term for stagnation heating, function of freestream Mach number
a	Sonic velocity, function of altitude
$\Delta L/L$	Free thermal expansion of radome material
E	Young's modulus of elasticity, function of temperature, for the radome material
ϵ_T	Infrared emissivity, function of temperature, for radome material
ϵ_D	Dielectric constant of the radome material, function of temperature
γ	Ratio of specific heats for air, function of temperature and pressure
h	Enthalpy of air, function of temperature and pressure
k	Thermal conductivity of the radome material, function of temperature
M/M_o	Mach number ratio across shock wave for definition of local flow conditions, function of freestream Mach number
M_o	Freestream Mach number variable
P_o	Freestream static pressure, function of altitude
P/P_o	Pressure ratio across shock wave for definition of local flow conditions, function of Mach number
Pr	Prandtl number for air, function of temperature and pressure
Q_{EXT}	Values of heat flux from externally controlled sources, functions of time
ρc_p	Product of density and specific heat for radome material, function of temperature
R	Radius coordinate for use in geometry descriptions
θ, ϕ	Angle coordinates for use in cylindrical and spherical geometry descriptions
T_o	Freestream static temperature, function of altitude
T_{EXT}	Externally controlled temperature values, functions of time
T	Temperature variable
τ	Time variable, the independent variable for the problem solution
μ	Viscosity of air versus temperature and pressure
V	Missile velocity, function of time
x,y,z	Cartesian coordinates for geometry descriptions
Z	Altitude as an independent variable and as function of time
Z*	Compressibility factor of air, function of temperature and pressure
C_{N_R}	Normal force coefficient at radome vs angle of attack and Mach number
C_{N_M}	Normal force coefficient of missile vs α & Mo
C_{A_R}	Axial force coefficient of radome vs α & Mo
X_{cp}/L	Ratio of location of center of pressure to total radome length

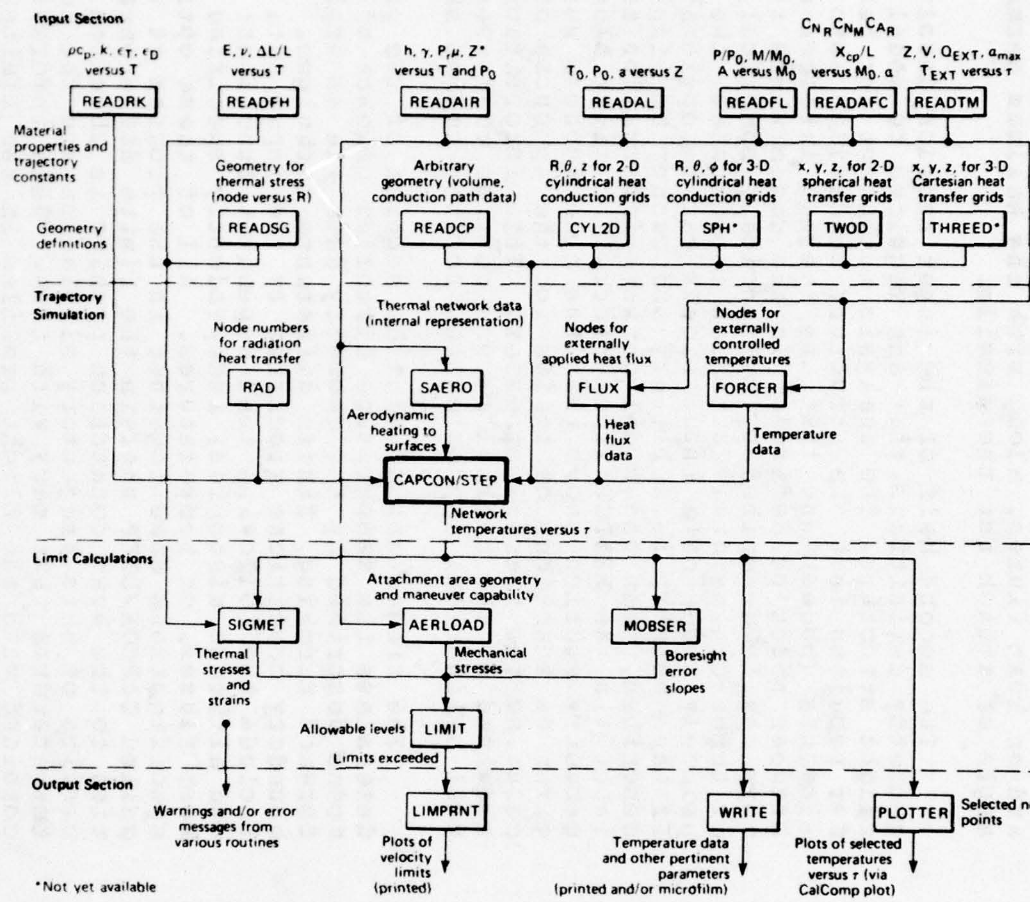


Fig. 3 Overall Data and Control Flow for URLIM Program

and/or heat fluxes, along with the maximum permissible angle of attack for the missile.

The second half of the input section involves the geometry definitions that are required to model the flight structure. The analysis technique for heat transfer requires that the structure be divided into smaller elements (nodes) and that the thermal interconnection between nodes be defined. In the cases where the structure may be described by cylindrical, spherical, or two- or three-dimensional Cartesian coordinates, the appropriately named data input blocks can be optionally used. If the geometry is arbitrary and cannot be simply described, then the nodal network information may be input via the READCP input block. The first block in the geometry section shows that the node numbers must be given as functions of radius for the purpose of calculating the thermal stresses. This information is required by the thermal stress routine that uses a thick wall cylindrical approximation for the radome shape.

The trajectory simulation section of the program determines the temperature histories of each of the nodes described by the geometry data via an explicit, forward marching, finite difference technique. The boundary conditions specified by the input data can include the following time-dependent functions: velocity and altitude histories, independently specified nodal heat fluxes, or temperatures. All of these optional specifications come together in the program at the block called CAPCON/STEP wherein the finite difference solution to the heat conduction problem is obtained. The results of this trajectory simulation are the nodal temperatures that vary with time. This information is combined with the flight profiles in the Limits section to provide the thermal stresses, the aerodynamic load information, and the boresight error rates. During a run of the URLIM program the four limits (including melting) are monitored; when excessive values are reached they are noted by the LIMIT block routines and saved for later printout.

The last section of Fig. 3 is concerned with the program's output. The first output is the error/warning messages that may be generated during the execution for any of a variety of reasons. The next output is the printer generated plots of the combined limits data, samples of which are given in Figs. 4 and 5. These

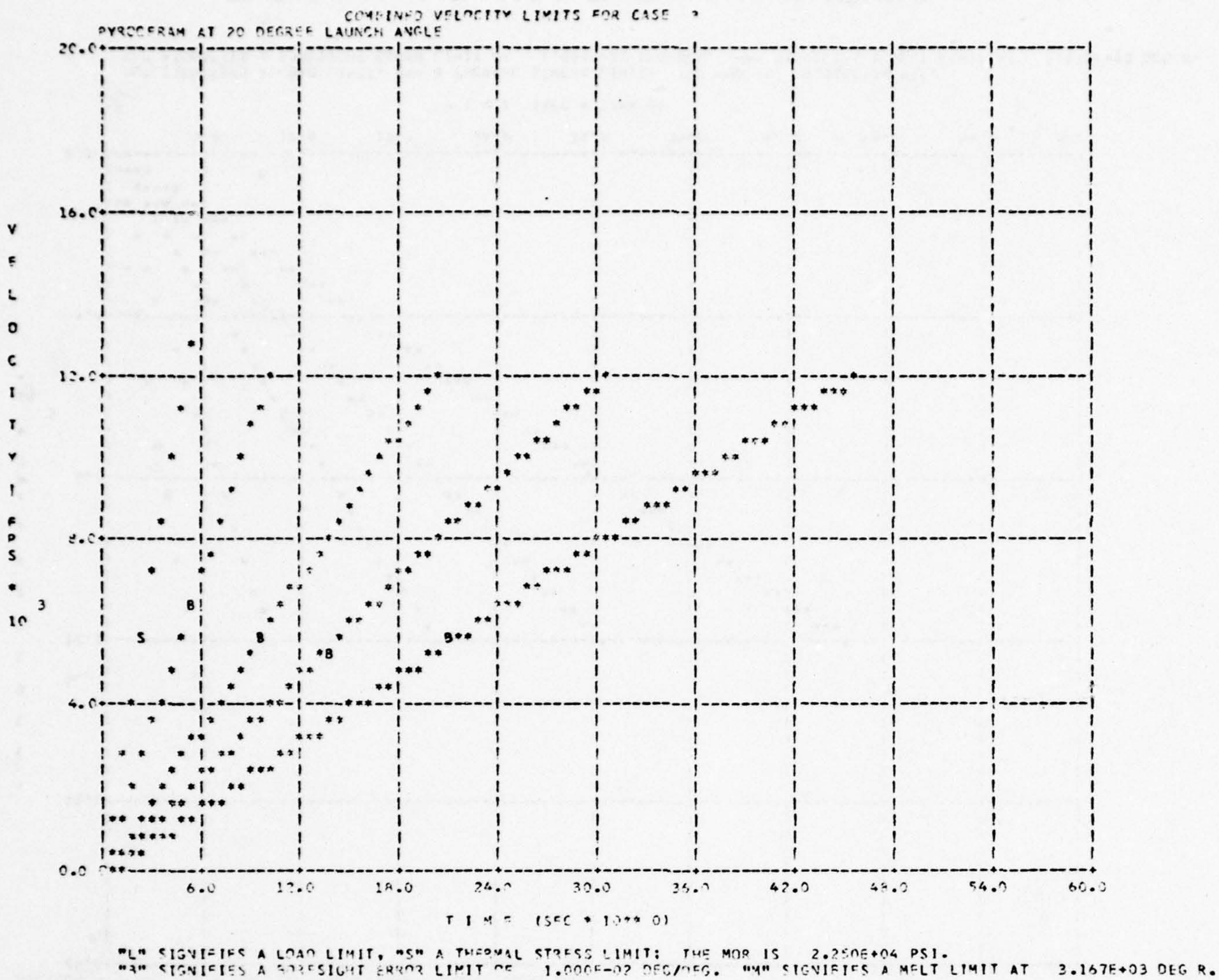
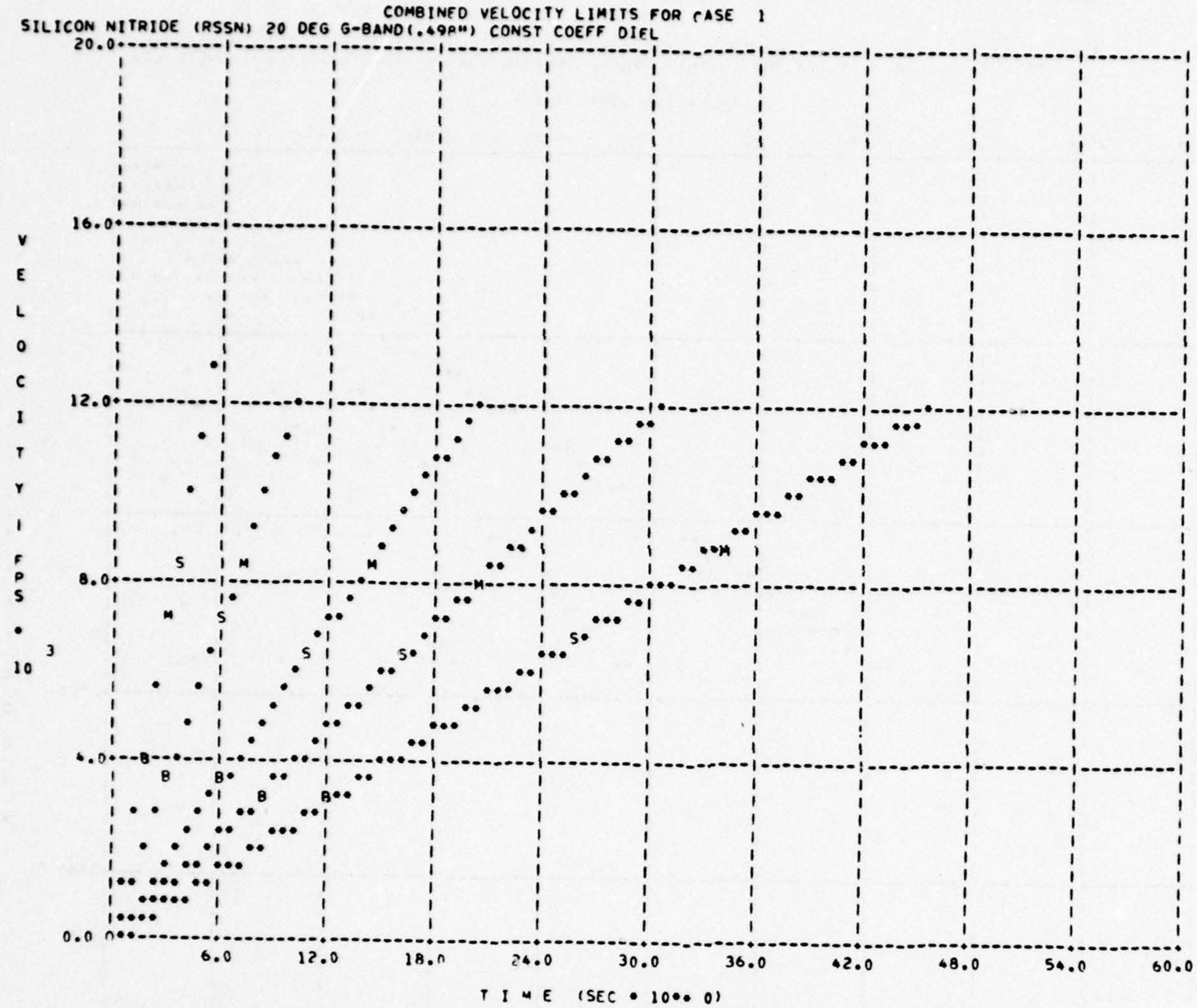


Fig. 4 Example of a Combined Velocity Limit Plot Generated by URLIM.



"L" SIGNIFIES A LOAD LIMIT, "S" A THERMAL STRESS LIMIT; THE MOR IS 2.000E+04 PSI.
"B" SIGNIFIES A BORESIGHT ERROR LIMIT OF 1.000E-02 DEG/DEG. "M" SIGNIFIES A MELT LIMIT AT 3.870E+03 DEG R.

Fig. 5 Example of a Total Limits Plot Generated by the URLIM Program

plots, which were run for a sample problem that will be discussed below, show the set of trajectories examined plotted (with asterisks) as velocity versus time. The letters printed on the trajectories indicate the occurrence of one of the four limits. The locus of the lowest of these points delineates the permissible operating regime for the particular radome modeled during the run. Although this output is somewhat inaccurate due to the method of plotting (line printer) it is a very handy and concise way of reading the results of the URLIM run. The output block WRITE prints all of the other data as it is calculated. In the case of a very large and/or very long run, this output may be put on microfiche. The final output block provides the capability for having off-line CalComp plots made of selectable parameters (e.g., temperatures, stresses, boresight errors, electrical wall thickness changes, or mechanical load stresses) as functions of time.

Sufficient generality has been built into URLIM to allow virtually any type of thermal analysis. For example, as many as nine different materials may be flown on any number of user-defined trajectories and any combination of the four basic limits may be determined. Such a run could use all of URLIM's capability. On the other hand it may be required simply to take some experimental data, such as front face temperature versus time on a cylinder, and to determine the thermal stresses that result. Such a problem is easily modeled with URLIM and the CalComp plotter routines can provide the required thermal stress history in graphical form. In summary, the URLIM program can be used to almost any degree of complication because its basic computational units are under the user's control to be selected as required.

The sample problem that will be used for illustrative purposes in the next section was assembled to demonstrate the versatility of the URLIM program. The problem involves determining the combined velocity limits of three materials (alumina, fused silica, and Pyroceram 9606) over the 10 trajectories mentioned earlier (c.f. Fig. 2b). A K-band radar frequency of 30 GHz was used for purposes of wall thickness calculations. The three resultant nodal breakups are shown in Fig. 2c.

It should be noted that simulating the ten trajectories for each of the three materials implies running a total of 30 separate thermal models. It is therefore necessary to create 30 separate and uniquely numbered groups of thermal nodes and fly each of them on its respective trajectory. With the basic scope of the sample problem now stated, a description of the precise inputs required to solve this problem is given.

3. REQUIRED INPUTS

Before an URLIM run can be made the user must have (1) an IBM System 360 or 370 computer available to him and (2) a copy of the completely executable URLIM code. Given these two essentials the user must assemble a series of job control language (JCL) statements and data cards that will access the URLIM program via the operating system (OS) at the computer center. The examples of JCL that are included with this report will be ones that apply to the 360/91 computer at the Applied Physics Laboratory using OS/MVT under control of ASP (The Asymmetric Multi-processing system). Further descriptions of OS and JCL are found in "Interface with the Operating System", in Section 3 of Volume 1.

Figure 6 shows the sequence of JCL used to run the sample case that will be referred to throughout this report. For the moment, we will concentrate only on the first few cards that deal with accessing the URLIM program. The first card is the JOB card and contains user and job identification information along with accounting data that is generic to the APL computer center. The second JCL statement is the execute (EXEC) statement:

```
//      EXEC      PGM=URLIM,
//                REGION=240K,TIME=10,
//                PARM='ISASIZE(68K),REPORT'
```

These cards specify to the operating system that the program URLIM is to be executed, that it will require 240 000 bytes of storage and will run for no more than 10 minutes. Additionally a parameter is passed to the program on this card specifying an Initial Storage Area (ISASIZE) of 68 000 bytes and that a report is asked for. These two parameters, which are important to efficient execution of the program, will be described in detail later (c.f. "Dynamic Storage" in Section 3 of Volume 1). The third JCL statement indicates the data set that contains the program URLIM:

```
//KELLY#1  JOB   (11116,C,U,N),'KELLY FRAZER',NOTIFY=FRAZER X7416
//    EXEC       PGM=URLIM,
//               REGION=240K,
//               TIME=10,
//               PARM='ISASIZE(68K),REPORT'
//STEPLIB   DD   DSN=BBE.FRAZER.URLIMALL,DISP=SHR
//SYSPRINT  DD   SYSOUT=A,
//               DCB=(RECFM=VBA,LRECL=137,BLKSIZE=3155)
//PLIDUMP   DD   SYSOUT=A
//SYSIN     DD   DSN=BBE.FRAZER.SAMPLIN,DISP=SHR
//          DD   *
     :
/*
//FLORATS   DD   DSN=BBE.FRAZER.MHWDATA(VK2114),DISP=SHR
//FORCOEF   DD   DSN=BBE.FRAZER.MHWDATA(AFCOEF),DISP=SHR
//ATMOS     DD   DSN=BBE.FRAZER.MHWDATA(ATMOS),DISP=SHR
//AIR       DD   DSN=BBE.FRAZER.MHWDATA(AIR7X28),DISP=SHR
//LIMPLT    DD   DSN=BBE.FRAZER.LIMPLT01,
//               SPACE=(3124,(2,0),RLSE),
//               DISP=(NEW,CATLG),
//               UNIT=SAVE
//MAXPRNT   DD   SYSOUT=A,
//               DCB=(RECFM=VBA,LRECL=137,BLKSIZE=3155)
```

Fig. 6 JCL Statements Required to Run Sample Problem

```
//STEPLIB     DD   DSN=BBE.FRAZER.URLIMALL,
//                 DISP=SHR
```

The data set name (DSN) on this STEPLIB card indicates that the partioned data set BBE.FRAZER.URLIMALL is the data set that must contain a member named URLIM. The fourth JCL statement describes the basic output file SYSPRINT and shows via the SYSOUT=A specification that the output will be on standard computer paper. A provision has been made to receive this output on microfiche and is used by simply specifying SYSOUT=Q rather than SYSOUT=A for the particular print file in question. (This option is available in this way at the APL computer center). The other JCL statements all describe input or output files that are needed by the program during execution; their application will become evident as the required input is further described. In general, the required input data can be read from the standard input file (SYSIN) or from other files of the user's specification. (Appendix A gives a description of the data input formats that are used by the program and referred to below.) The first data cards that are read by the URLIM program are basic control values that allow the user to specify what analysis will be made. These values are read from the SYSIN file only and are expected to be in the PL/I DATA format; that is, the variable values are given in the form

variable name = value

in sequence seperated by a comma or one or more blanks until a semicolon is encountered. All of the possible control variables have specific default values, as shown in Table 1. The significance of these variables and their values will become clear in the subsequent explanations. Because they must be the first data input to the program they are given here with brief explanations. If no value is specified for one of these variables, then the default value will apply.

Table 1

URLIM Control Variables

Variable	Default Value	Use
CALLARO	0	Number of separate aerodynamic heating blocks
CALLLOD	0	Number of individual load calculations
CALLSIG	0	Number of separate thermal stress calculations
CALLBSE	0	Number of separate boresight error calculations
CALLCYL	0	Number of thermal networks that are two-dimensional cylindrical
CALLCL3	0	Number of thermal networks that are three-dimensional cylindrical
CALLFLO	0	Number of separate aerodynamic flow tables to be read in
CALLLIM	0	Number of combined limit plots to be made
CALLTOD	0	Number of nodal networks that are two-dimensional Cartesian
CALLTIM	0	Number of separate time tables to be read in
CALLFLX	0	Number of heat flux boundary conditions
CALLFRC	0	Number of fixed temperature boundary conditions
MANLIN	0	Flag indicating manual input of

Variable	Default Value	Use
		nodal parameters: 0 = NO INPUT, 1 = INPUT ON NETFILE
MAXENTS	0	Maximum number of entries to the mechanical property tables
MCPROPS	0	Number of mechanical property tables
MINPRNT	0	Flag for maximum print option: 1 = minimum print, 0 = regular print, 2 = minimum and maximum print
AIRPRNT	0	Flag for printing the air property tables: 1 = print them on SYSPRINT, 0 = no print
MINRUN	0	Flag for minimum execution option: 1 = minimum run; 0 = maximum run
PLOTS	0	Flag for CalComp plots; 0 = no plots, 1 = plot information will be saved
THPROPS	1	Number of material thermal property tables
XCAPLIM	20	Highest thermal node number
#MACH	0	Number of Mach number entries to aerodynamic force tables
#NODES	0	Total number of thermal nodes
#SET	0	Number of nodes to be initialized to a set temperature
STARTIM	0	The initial trajectory simulation time (s)
STOPTIM	10	The final trajectory simulation time (s)

Variable	Default Value	Use
SIGLIST	0	Flag for specifying input format for radius-node-temperature data for thermal stresses
TINIT	0	The initial temperature for all nodes except those set specifically
#ALPHA	0	Number of angle of attack data points in aeroforce tables
TAIRFACT	1	Converstion factor for air temperature values to convert to °R
HAIRFACT	1	Conversion factor for air enthalpy tables to convert to Btu/lbm
MAXSTEP	1	Maximum allowable time step (s)
MINSTEP	0.05	Minimum allowable time step (s)
PALTFACT	2115.36	Conversion factor for pressure versus altitude tables to convert to lbf/ft^2
PAIRFACT	2115.36	Conversion factor for pressure variable in air property tables to convert to lbf/ft^2
NETFILE	'SYSIN'	File name for specified nodal information
AFCFILE	'SYSIN'	File name for aerodynamic force data
TREF	536	Reference temperature for all enthalpies (°R)
TALTFACT	1	Conversion factor for temperatures in the altitude tables to convert to °R

In the second major input section the material properties are read in. The thermal transport properties are read in first for each material followed by the mechanical properties (elastic modulus, Poisson's ratio, free thermal expansion). The formats are described in the following paragraphs.

THERMAL PROPERTIES

There must be a number of data groups equal to the value of the control variable THPROPS with the following structure:

1. On the SYSIN file there must be a card (or cards) in LIST format with:

   a. a file name,

   b. the number of table entries to be read, and

   c. the maximum allowable boresight error for this material.

2. On the file named in a (above) there must be data values that will be read as: two comment cards (160 characters) followed by the number of cards specified in b (above), with the following information on each:

Cols	Value
1-14	Temperature (°R), F-format;
15-19	Density times specific heat (Btu/ft^3-°R), F-format;
30-44	Thermal conductivity (Btu/ft-h-°R), F-format;
45-59	Infrared emissivity, F-format;

Cols	Value
60-69	Dielectric constant, F-format;
70-80	Loss tangent, F-format.

Material code numbers starting with 1 and running serially to THPROPS will be associated with each group of thermal properties. In Appendix B the sample input shows that the thermal properties of three materials were read from the SYSIN file. The sample output in Appendix C shows that the three material codes were assigned in order and that all of the input values were printed out and reformated. It is important to note that the last temperature value listed in each thermal property table is used as the melt temperature for the particular material. Also, the temperatures must be listed in monotonically increasing order.

The thermal properties (with Rankine temperature scale dependence) are followed by the mechanical properties with Farenheit temperature scale dependence.

MECHANICAL PROPERTIES

There must be a number of data groups equal to the value of the control variable MCPROPS with the following format:

1. On the SYSIN file a card (or cards) in LIST format with:

    a. a file name,

    b. the number of table entries, and

    c. the maximum allowable bending stress (the modulus of rupture).

2. In the file named in a (above) there must be as many values of temperature, modulus, Poisson's ratio, and free thermal expansion as specified in b (above) with the following format: two comment cards (160 characters) followed by data cards:

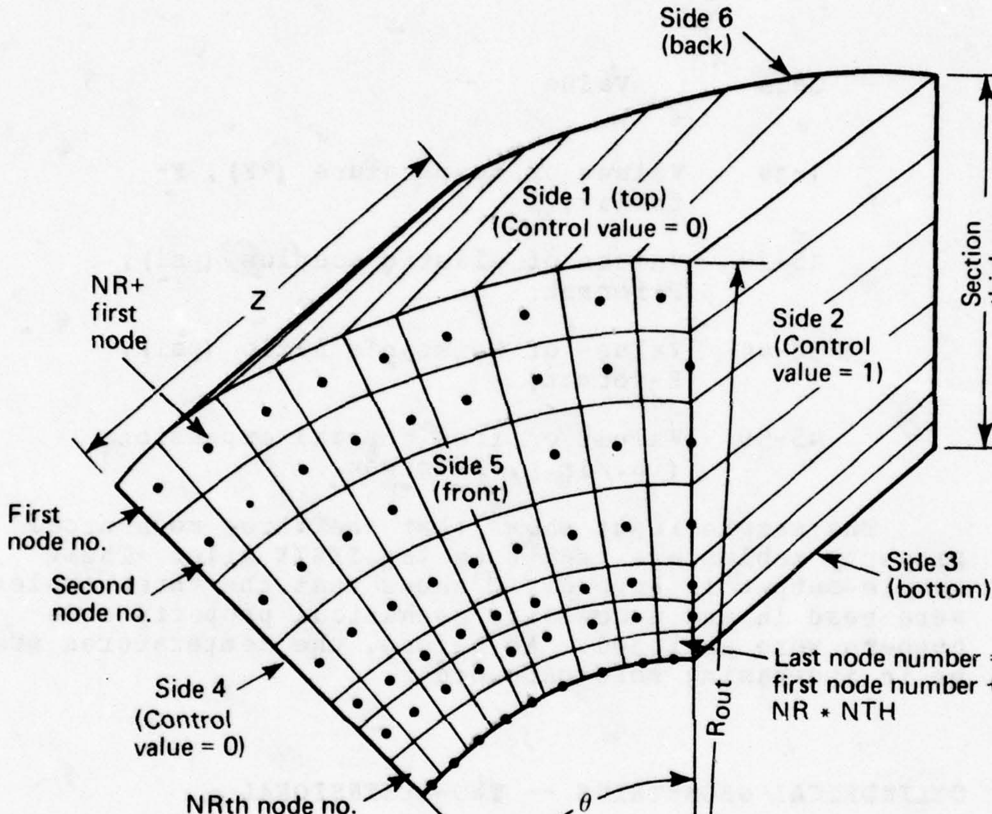
Cols	Value
1-14	Values of temperature (°F), F-format;
15-29	Values of elastic modulus (psi), E-format;
30-44	Values of Poisson's Ratio (psi), E-format;
45-59	Values of free thermal expansion (in./in.), E-format.

The sample input shows that the three mechanical property tables are read from the SYSIN file. The sample output in Appendix C shows that the three tables were read in and successive mechanical property code numbers were assigned. As before, the temperatures must be in increasing monotonic order.

CYLINDRICAL GEOMETRIES -- TWO-DIMENSIONAL

The next several cards in the sample input section are the control cards for obtaining automatically generated cylindrical geometries. The control variable CALLCYL controls the number of such nodal definitions to be made. In the sample case, CALLCYL was set to 30 in the initial input so there are 30 sets of data on the SYSIN file in this section, each with the following data in LIST-format (c.f. Fig. 7):

Item	Value
1	NR, the number of radial divisions for the cylindrical section;
2	NTH, the number of circumferential divisions in the section;
3	ROUT, the outer radius of the section (ft);



Notes:

- All dimensions must be in feet or degrees
- Node numbering begins at upper left corner ($\theta = 0$, $R = R_{out}$) and counts first radially and then circumferentially.
- The node centers (small dots) are used for computation of the thermal path lengths between nodes and are located at the geometric center of gravity except for boundary or side nodes. When the control valve is set to 1 for a side then the node centers are considered to be at the external surface for computations of thermal path length.
- List of angular and radial spacings can be arbitrary or equally spaced according to values input (see text for explanations).

Fig. 7 Cylindrical Section Geometry Conventions

Item	Value
4	Z, the depth of the section, Z-axis dimension (ft);
5	Thermal property code number for the material in this section;
6	The node number for the first node in the array of nodes (c.f. Fig. 7 for the convention used to number the nodes);
7-10	Four numbers (either 0's or 1's) that indicate the type of nodal connection to use on each of the four sides of the cylindrical section;
11	A list of NR numbers specifying the radial thickness to be used in the section starting from the surface and proceeding inward (if NR is 1, then the first number input here is taken to be the total radial thickness of the section; it is followed by a second number that indicates the number of evenly spaced radial divisions to be used for the section; length or radius values are in feet); and
Next	A list of NTH numbers specifying the angular divisions to be used in the circumferential direction (deg) (if NTH is set to 1, then the first number here is the total angle of the section and the next input value is the number of evenly spaced divisions that are required).

The sample input of Appendix B shows the 30 groups of data that were input and the sample output shows the 30 cylindrical node geometries that were generated. Note that the surface nodes are not generated in this computation (they are input later via the manual nodal input). This is not to say that these surface nodes could not have been input through this section. To do so the nodal thickness is simply entered as zero. This method was not done in the sample problem so as to illustrate the use of the manual input feature described in a subsequent paragraph.

CYLINDRICAL GEOMETRIES -- THREE-DIMENSIONAL

If the control variable CALLCL3 is set to a non-zero value then that number of data groups will be read from the SYSIN file. These data will describe three-dimensional cylindrical node geometries. The required inputs for this automatic network generator are very similar to those for two-dimensional networks as described above. Specifically, for each network there must be the following data in list format on the SYSIN file: (c.f. Fig. 7)

Item	Value
1	NR, the number of divisions to be made in the radial direction;
2	NTH, the number of divisions to be made in the circumferential direction;
3	NZ, the number of divisions to be made in the axial direction;
4	ROUT, the outer radius of the secton;
5	Thermal property code for the material comprising this section;
6	The node number of the first node in this section;
7-12	Six numbers (either 0's or 1's) that indicate the type of conductance path to be used on each of the section's six sides;
13	A conversion factor that will be multiplied times each input variable that is a spatial dimension so as to obtain units of feet as a result;
14	A list of NR numbers specifying the series of radial thicknesses to be used (this item is interpreted identically to the list of thicknesses used by the two-dimensional routine (above));

Item	Value
Next	A list of NTH numbers specifying the circumferential divisions to be used in the section (deg) (this list is interpreted the same as the list of circumferential divisions used by the two-dimensional cylinder routine (above));
Next	A list of NZ numbers specifying the axial thicknesses to be used in this section (this list is interpreted in the same manner as the two previous lists).

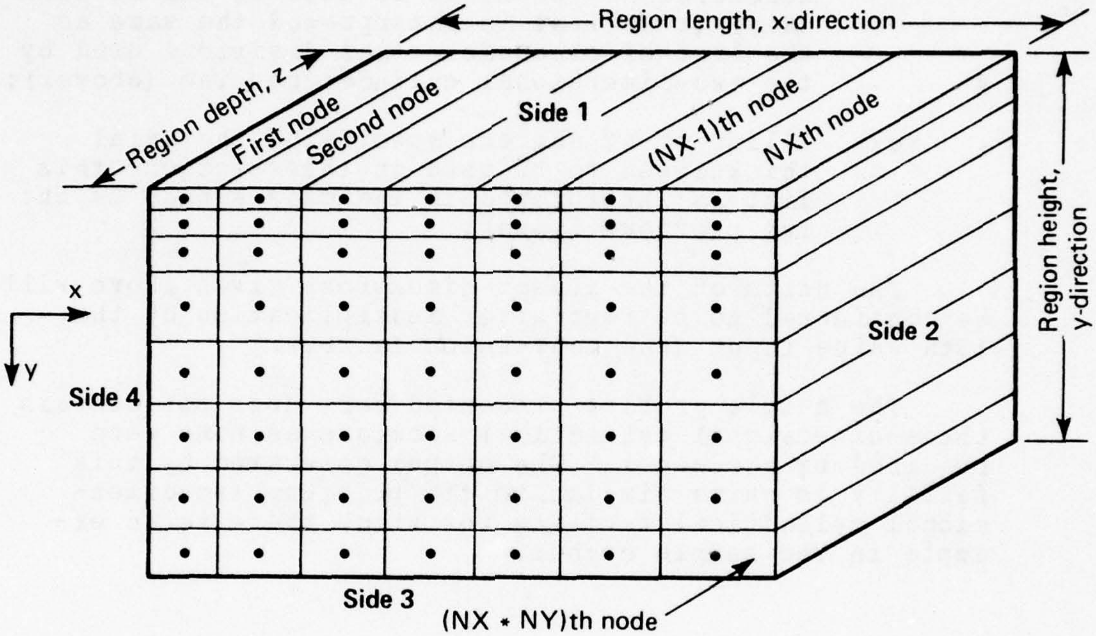
The units of the linear dimensions given above will be considered to be feet after multiplication by the 13th value input (the conversion factor).

The sample problem presented here does not contain three-dimensional cylindrical sections as none were required by the model. The output generated by this facility is quite similar to the previous two-dimensional cylindrical facility for which there is an example in the sample output.

RECTANGULAR GEOMETRIES

If the control variable CALLTOD is set to a non-zero value then that number of data groups will be read from the SYSIN file. These data will describe two-dimensional Cartesian node geometries. The required inputs for this automatic network generator are very similar to those for the cylindrical geometries. Specifically, for each two-dimensional grid network there must be data cards in the SYSIN file with the following information: (c.f. Fig. 8)

Item	Value
1	NX, the number of division to be made in the x-direction;
2	NY, the number of divisions to be made in the y-direction;



Notes:

- All dimensions must be in feet
- Node numbering begins at upper left corner (x = 0, y = 0) and counts first in x-direction and then in y-direction.
- The node centers (small dots) are used for computation of the thermal path lengths between nodes and are located at the geometric center of gravity except for boundary on side nodes: when the control value is set to 1 for a side then the node center is taken to be at the external edge of the node for computation of thermal path length.
- The list of angular and radial spacings can be arbitrary, or equally spaced according to input values (see text for explanations).

Fig. 8 Two-Dimensional Cartesian Node Network

Item	Value
3	Z, the depth of the nodal grid in the z-direction (ft);
4	Material property code for thermal transport properties;
5	The node number of the first node, (c.f. Fig. 8 for node numbering conventions);
6-9	Four numbers (0's or 1's) that select the type of nodal connections for boundary nodes;
Next	A list of NX numbers specifying the x-direction thickness to be used by the automatic geometry routine (if NX is 1, then the first number in this list is the total length of the region in the x-direction and the next number is the number of equally spaced nodal divisions that will be used) (ft); and
Next	A list of NY numbers specifying the y-direction thicknesses to be used by the automatic geometry routine (If NY is 1 then the first number in this list is assumed to be the total length of the region in the y-direction and the next number is the number of equally spaced nodal divisions that will be used within the y-direction thickness) (ft).

In the sample problem the control variable CALLTOD was not set, so the default value of zero was used; i.e. no two-dimensional Cartesian node regions were required and no two dimensional cards were read. However, had there been any cards read, tables similar to the ones for the cylinder input would be printed on the output file for verification of the input values.

The current version of URLIM does not have the spherical or three dimensional Cartesian node geometry routines in it. In a subsequent release of the URLIM program these routines will be available and the input for them will occur at this location in the SYSIN file and will be controlled with the variables CALLSPH and CALL3D.

GEOMETRY TABLE

If the control variable MANLIN is set to 1 then the file specified by the NETFILE variable will be read for thermal network data. This data must be in the following format:

Two comment cards (160 characters) followed by a variable number of network data cards that describe nodal interconnections in the following format:

Columns	Item
1-4	Node number, F-format;
10-19	Node volume (ft^3), E-format;
20-29	Node thermal property identification number associated with thermal property tables read in earlier, F-format;
30-39	The number of interconnections between this node and its immediate neighbors, F-format;
40-49	The node number for the first interconnection, F-format;
50-59	The thermal path length (area/distance) between node centers (ft), E-format;
60-69	The node number of the next immediately connecting node (if present), F-format; and
70-79	The thermal path length between the node and its next connecting node (if any) (ft), E-format.

There may be as many entries to this table as required for the model and they may be in any order. The end of the list of cards is indicated by including a card with columns 1-4 blank or a zero. Moreover, if any datafield is left blank, a zero will be assumed for the value. The sample input of Appendix B shows that the surface nodes for all the aerodynamic heating conditions were read from the SYSIN file. These particular nodes have zero volume (they are actually surfaces) and are

connected to structural nodes as indicated by the data entries. The sample output data in Appendix C shows a listing of the read in data values, again slightly reformatted.

The routine in URLIM that reads and processes the manual geometry input (READCP) has the capability of connecting nodes with radiation heat transfer as well as joining of different materials through a contact resistance. Also, any one node may be described as having connections to any number of other nodes by means of a special input procedure. Details of this capability are found in Appendix F.

AERODYNAMIC HEATING SPECIFICATIONS

If any aerodynamic heating calculations are to be made then the control variable CALLARO should be set to indicate how many different aerodynamic surfaces or "blocks" there will be. (An aerodynamic block is actually a set of surface (zero-volume) nodes that are subjected to the same aerodynamic condition. Usually, when there is more than one node to a block, the surface nodes are part of a two-dimensional thermal network that is subjected to the same aerodynamic environment over its entire surface.) Having CALLARO set to a nonzero value will cause the program to expect several groups of data to occur in the SYSIN file directly after the last geometry cards. These data in LIST format are:

<u>Air Property Data</u>

Item	Value
1	A file name indicating where a table of thermal and mass transport properties of air will be found;
2	The number of pressure entries in this table; and
3	The number of temperature entries in this table.

If the file named in item 1 (above) is SYSIN then the above values are followed immediately with a table of air properties in the following format: two comment cards (160 characters) followed by data cards:

Columns	Item
1-10	Value of pressure, F-format;
11-20	Value of temperature, F-format;
21-30	Value of enthalpy at the respective pressure and temperature, F-format;
31-40	Value of Prandtl number at the respective pressure and temperature, F-format;
41-50	Value of the ratio of specific heats for air, F-format;
51-60	Value of viscosity (lbm/ft-s) F-format; and
61-70	Value of compressibility for air, F-format.

If the file named in 1 (above) is other than SYSIN, then the two comment cards and the tabular data cards should be on the file associated with that file name, in the format stated above. The logical records of that file will be expected to be at least 80 characters. The physical units of the pressure, temperature, and enthalpy values were not specified in the definitions above because they may be variable and may be chosen by the user. However, it must be remembered that the control variables PAIRFACT, TAIRFACT, and HAIRFACT will be multiplied by each of the pressure, temperature and enthalpy values actually read and the resultant values will be assumed to have the following units: pressure, lbf/ft²; temperature, °R; and enthalpy, Btu/lbm.

The total number of air property data cards read during this phase will be the number of pressure entries (item 2 (above)) times the number of temperature entries (item 3 (above)). The pressure and temperature values must be in monotonically increasing order; i.e. all of the data cards at the lowest pressure must be first and they must have temperature values in increasing order. The next set of pressure cards must contain the same number of

temperature cards as before and the pressure value must be higher. Also, each set of temperatures must be the same; if they are not, a warning message will be printed and the temperature values from the first set of pressure cards will be used.

The sample problem input in Appendix B shows that the control card for this section of data names the file "AIR" as containing the air property data at 7 pressures and 28 temperatures. The sample JCL in Fig. 6 shows that the file named AIR is associated with the data set BBE.FRAZER.MHWDATA(AIR7X28) and the data that were read are shown reprinted in the sample output with the appropriate conversion factors already applied.

Atmosphere Definitions

The next set of input data values on the SYSIN file controls the reading of the atmosphere data for the aerodynamic calculations. These data are read if CALLARO is greater than zero. The data that will be required at this location on the SYSIN file (in LIST FORMAT) are:

1. A file name, and

2. The number of tabular entries to the atmosphere table.

If the file name in item 1 (above) is SYSIN then the immediately following cards on the SYSIN file will be the atmosphere table and should have the following format: two comment cards (160 characters) followed by data table cards:

Columns	Value
1-15	Value of altitude (ft), F-format;
16-30	Value of static temperature at the corresponding altitude, F-format;
31-45	Value of static pressure at the corresponding altitude, F-format;

Columns	Value
46-60	Value of the speed of sound at the corresponding altitude (ft/s), F-format; and
61-75	Value of the effective space temperature for use with radiation relief from the aerodynamically heated surfaces (°R), F-format.

If the file name mentioned in item 1 (above) is other than SYSIN then the two comment cards and the tabular data cards must be in a file associated with this other file name. The static temperature and pressure values read by this section of URLIM are multiplied by the control variables TALTFACT and PALTFACT respectively and the resultant values will be assumed to have the following units: temperature, °R; and pressure, lbf/ft^2

In the sample problem the control card for the atmosphere data names the file ATMOS as containing 30 data card entries describing the atmosphere model to be used. The sample output (Appendix C) shows the data read by this section with the conversion factors applied. The data were read from the data set BBE.FRAZER.MHWDATA(ATMOS) which is associated with the file name ATMOS in the JCL for the sample job (c.f. Fig. 6).

Aerodynamic Heating Parameters

The next data required by the program are a series of data groups describing the aerodynamic heating parameters. When the control variable CALLARO is nonzero then there should be CALLARO number of these data groups on the SYSIN file with the following data in LIST format (c.f. Fig. 9 for definition of terms):

Item	Value
1	The number of surface nodes in the aerodynamic heating block;

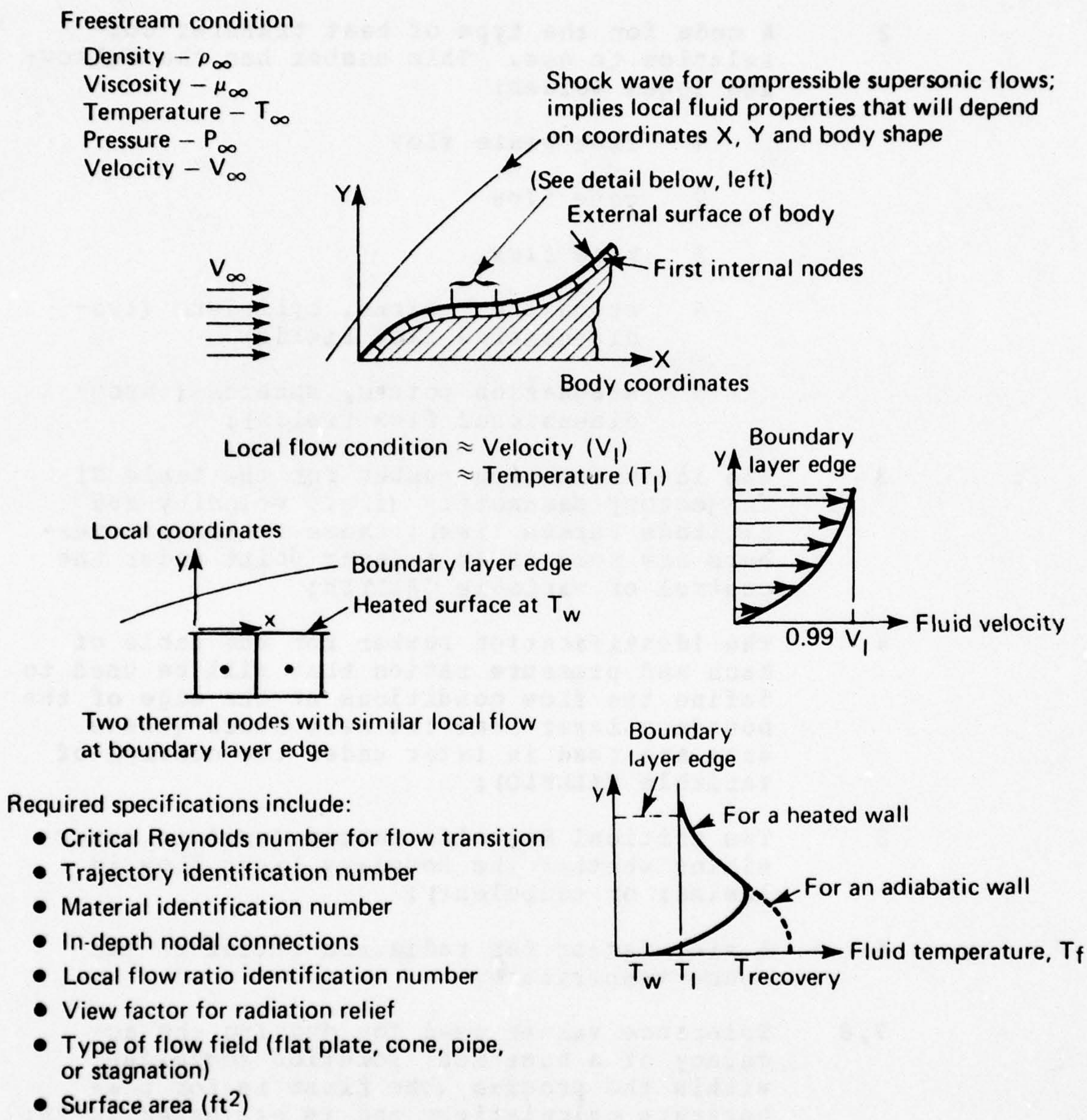


Fig. 9 Terminology for Aerodynamic Heating Boundary Conditions

Item	Value
2	A code for the type of heat transfer correlation to use. This number has the following legal values: 1 flat plate flow 2 cone flow 3 pipe flow 4 stagnation points, cylinders (two-dimensional flow fields) 5 stagnation points, spheres (three-dimensional flow fields);
3	The identification number for the table of trajectory parameters (i.e., velocity and altitude versus time); these tables and numbers are read in at a later point under the control of variable CALLTIM;
4	The identification number for the table of Mach and pressure ratios that will be used to define the flow conditions at the edge of the boundary layer near the aero block (these data are read in later under the control of variable CALLFLO);
5	The critical Reynolds number (used in determining whether the boundary layer flow is laminar or turbulent);
6	A view factor for radiation relief to the space temperature;
7,8	Tolerance values used for judging the accuracy of a numerical solution technique within the program (the first is for temperature calculations and is expressed in °R; the second is a heating rate value used to determine heat balances across the shock wave and across the heated surface and is expressed in Btu/ft^2-s; typical values for each are 1°R and 1 Btu/ft^2-s);

Item	Value
9	An iteration limit to be used for the numerical solutions mentioned above (if, after the specified number of iterations either of the convergence criteria are not met, then an appropriate message will be printed and the execution will continue; descriptions of the solution techniques and error messages are found in Appendix E);
10	For each of the surface nodes in the block (item 1 above) the following must be specified:

a. the surface node number,

b. the connecting, in-depth, node number,

c. the surface area (ft^2),

d. the reference length (ft), and

e. the diameter-to-length ratio (this item used for laminar pipe flow calculations only but some value must be supplied; when other than pipe flow is called for by item 2 (above), this value is not used.

In the sample input table (Appendix B) there are 30 cards with the above information. The first such card indicates that the first aero block will have one surface node, that the flow will be calculated using flat-plate correlations, the trajectory information will come from time table No. 1, the local flow parameters will come from flow table No. 1, the critical Reynolds number is 1×10^6, and the view factor for radiation relief to space is 1. The tolerance levels for the numerical solutions are 2°R for temperature calculations and 1 Btu/ft^2-s for heat balance calculations; ten iterations will be allowed. The node number of the single surface node is 1 and it is connected to interior node number 2; the surface area is 1 ft^2, and the reference length from the stagnation point is 0.133 ft. The diameter-to-length ratio (not actually used) is specified as 1.

The sample output shows the values that were read in at this point printed on SYSPRINT for ready reference and verification.

Local Flow Definitions

The next section of input that is read (if CALLARO is nonzero) contains the data that pertain to the local flow conditions in the vicinity of the aerodynamic heating blocks. The number of groups of data that are read in this section is the value of the control variable CALLFLO. There should be CALLFLO number of groups of data in the following order on the file SYSIN (LIST format):

1. A file name indicating where the data table values are located, and

2. The number of tabular data points in the flow table

The next data read are the tabular values of the flow parameters; they are read from the file named in item 1 above. The format, assuming 80-character records (cards), is: two comment cards (160 characters) followed by the number of tabular data cards specified in item 2 above with the following format:

Columns	Value
1-14	Values of freestream Mach number, F-format;
15-29	Values for the ratio of local body station Mach number to freestream Mach number, F-format;
30-44	Values for the ratio of local body station static pressure to freestream static pressure, F-format; and
45-59	Values of the velocity gradient term used only in stagnation heat transfer analyses (if this space is left blank, a value of 1 will be assumed), F-format.

The sample input shows the file 'FLORATS' to contain 17 flow table entries and the values read (from the card file FLORATS) are shown reformatted in the sample output.

AERODYNAMIC FORCE COEFFICIENTS

The aerodynamic load information for the missile and the radome are next read in if the control variables #ALPHA and #MACH are both nonzero. The data will be read from the file identified by the control variable AFCFILE (default is SYSIN). The data should have the following in EDIT-format: two comment cards (160 characters) followed by #ALPHA groups of tabular data cards each containing #MACH cards in the following format:

Columns	Value
1-13	Value of angle of attack of the missile (deg), F-format;
14-26	Value of freestream Mach number, F-format;
27-39	Value of the normal force coefficient of the complete missile (CNM) at the corresponding angle of attack and Mach number, F-format;
40-52	Value of the normal force coefficient of the radome only (CNR), F-format;
53-65	Value of the axial force (drag) coefficient of the radome only (CAR), F-format; and
66-78	Value of the center of pressure location, measured from the tip of the radome and normalized to the length of the radome, F-format.

The sample input shows no input for this data section from the SYSIN file. Since the control variable AFCFILE was set to 'FORCOEF', this file is read for the tabular data. The sample output shows the table of data items printed out for inspection. Note that the indepen-

dent variables (angle of attack and Mach number) are both in monotonically increasing order.

AERODYNAMIC LOAD PARAMETERS

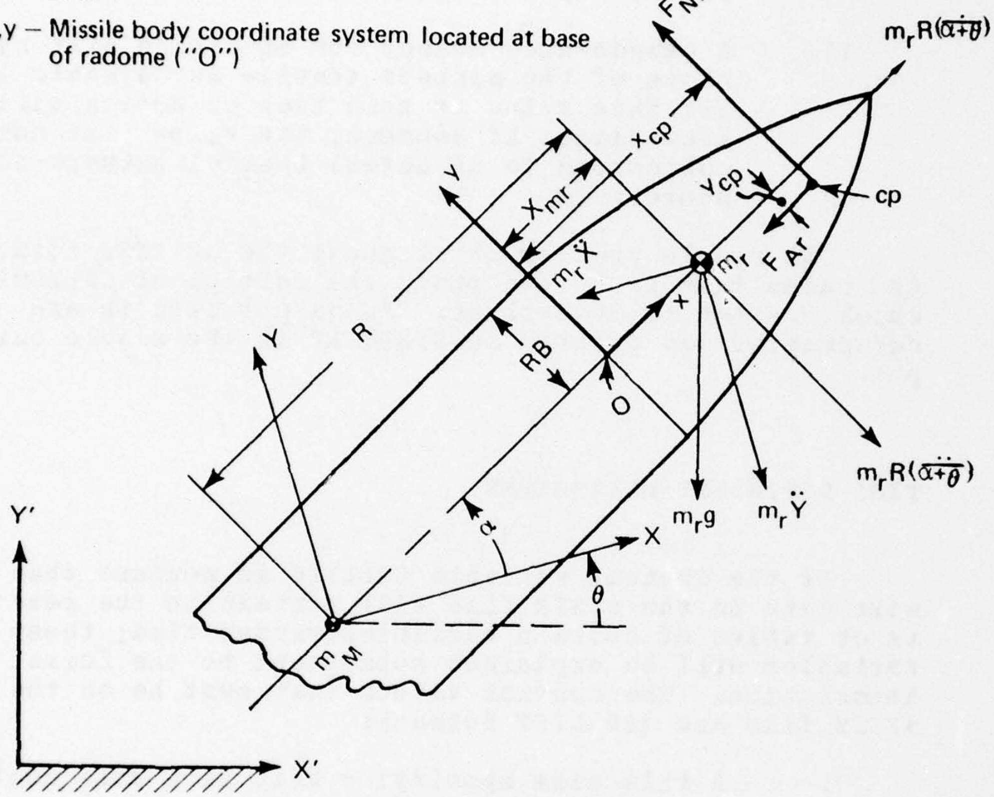
The next data required by URLIM is controlled by the variable CALLLOD, which tells how many aerodynamic load cases will be evaluated. The calculations using these data determine the missile-radome attachment stresses due to maneuver and pressure forces. On the file SYSIN there should be CALLLOD groups of data in the following order in LIST format (refer to Fig. 10 for nomenclature conventions):

Item	Value
1	Total length of radome (in.);
2	Radius of the radome base (in.);
3	Thickness of radome wall at the attachment ring (in.);
4	Location of the center of mass of the whole missile, measured from station zero (the tip of the radome) (in.);
5	Density of the radome material (lbm/ft^3);
6	Total weight of missile (lbm);
7	Maximum permissible lateral acceleration (ft/s^2);
8	Maximum permissible rate of change of angle of attack (deg/s);
9	Maximum permissible acceleration of angle of attack (deg/s^2);
10	An identification number for the trajectory table used for this flight simulation case (the trajectory table identification numbers are assigned when the time-dependent data are

X′,Y′ – Coordinate system attached to ground

X,Y – Coordinate system along and perpendicular to velocity vector of missile at center of mass of missile

x,y – Missile body coordinate system located at base of radome ("O")



m_M, m_r are the mass of the whole missile and radome only.

RB is the radome base radius

CP is the center of pressure on radome

α is the missile angle of attack

g is the gravitational acceleration

F_{Nr}, F_{Ar} are the normal and axial forces on the radome due to the dynamic pressure of the air stream

˙ and ¨ represent first and second derivatives with respect to time

⊖ Centroid of radome or missile

Fig. 10 Coordinate System and Forces for Radome Mechanical Load Analysis

Item	Value
	read in, under the control of variable CALLTIM.); and
11	A psuedo-node number for obtaining history plots of the maximum tensile aerodynamic load (if this value is zero then no action will take place; if nonzero, the value must not correspond to an actual thermal network node number).

The sample problem input shows the 30 LIST formatted cards that were read under the control of CALLLOD, which was set to 30 earlier. The values read in are reformatted and printed on SYSPRINT in the sample output.

TIME-DEPENDENT PARAMETERS

If the control variable CALLTIM is nonzero then the next data in the SYSIN file will pertain to the reading in of tables of certain variables versus time; these variables will be explained subsequent to the format description. The control values that must be on the SYSIN file are (in LIST format):

1. A file name specifying what file will contain the table of data and

2. The number of tabular data values to be read.

On the file named in 1 (above) there should be card images (80 character records) with the following data: 2 comment cards (160 characters) followed by the specified number of tabular data cards in the following EDIT format:

Columns	Value
11-9	Value of time (s), F-format;
10-19	First dependent variable, F-format;

Columns	Value
20-29	Second dependent variable, F-format;
30-39	Third dependent variable, F-format;
40-49	Fourth dependent variable, F-format; and
50-59	Fifth dependent variable, F-format.

Each of the CALLTIM tables will be assigned a serial identification number starting with 1. These identification numbers are then input by the user at other points in the data for the various routines requiring the particular data. For aerodynamic heating the required column format is:

Columns	Required Variable
1-9	Time variable (s);
10-19	Altitude values (ft);
20-29	Velocity (ft/s); and
30-39	Values of externally applied infrared radiation to the aerodynamic surface (Btu/ft^2-s).

In URLIM runs where the aerodynamic loading is calculated (CALLLOD ≠ 0) the values of the maximum permissible angle of attack must also be provided; e.g.:

Columns	Required Variable
40-49	Maximum permissible angle of attack (deg).

In the case where boundary conditions of temperature or heat flux histories must be input then the specific number of the column positions is not critical but the specific dependent variable number will be needed by other parts of the program. Further explanation of this aspect of the time-dependent data is given in the next section, where input for the temperature and heat flux boundary conditions is described.

The sample problem input shows 10 trajectory tables were read in as time-dependent input for the aerodynamic heating calculations (CALLTIM was set to 20.) The

control cards indicate that the tables are on the SYSIN file so that each table follows immediately each control card. (Note that the dependent variable ordering convention is adhered to and that the maximum permissible angle of attack is set in all cases to 20°.) The sample output shows each of the tables printed out and reformatted slightly. The serial identification numbers have also been assigned.

HEAT FLUX BOUNDARY CONDITIONS

The next input to the URLIM program is for externally supplied heat fluxes and is controlled by the variable CALLFLX. In the SYSIN file there should be CALLFLX number of data groups with the following items in LIST format:

Item Value

1. The identification number of the time table where the values of externally specified heat flux (Btu/ft^2-h) are fcund;
2. The dependent variable identification number within the above named table;
3. The identification number for the thermal property table of the material to which the flux is applied;
4. The number of thermal nodes to which the flux is applied; and
5. For each of the nodes to which the flux is applied, the following three values:
   a. the thermal node number;
   b. the surface area (ft^2); and
   c. the view factor to the radiation source.

In the sample problem, there are no heat flux boundary conditions (i.e., CALLFLX = 0) and so there is

no input to this section in the sample input. In the cases where heat flux data is input, the values are reformatted and printed on SYSPRINT for reference.

FORCED TEMPERATURE BOUNDARY CONDITION

If the control variable CALLFRC is set to a nonzero value then that number of sets of data values (in LIST format) must appear in the SYSIN data stream. These values are:

1. The identification number of the time table where the values of externally specified temperatures are found;

2. The dependent variable identification number within the above table;

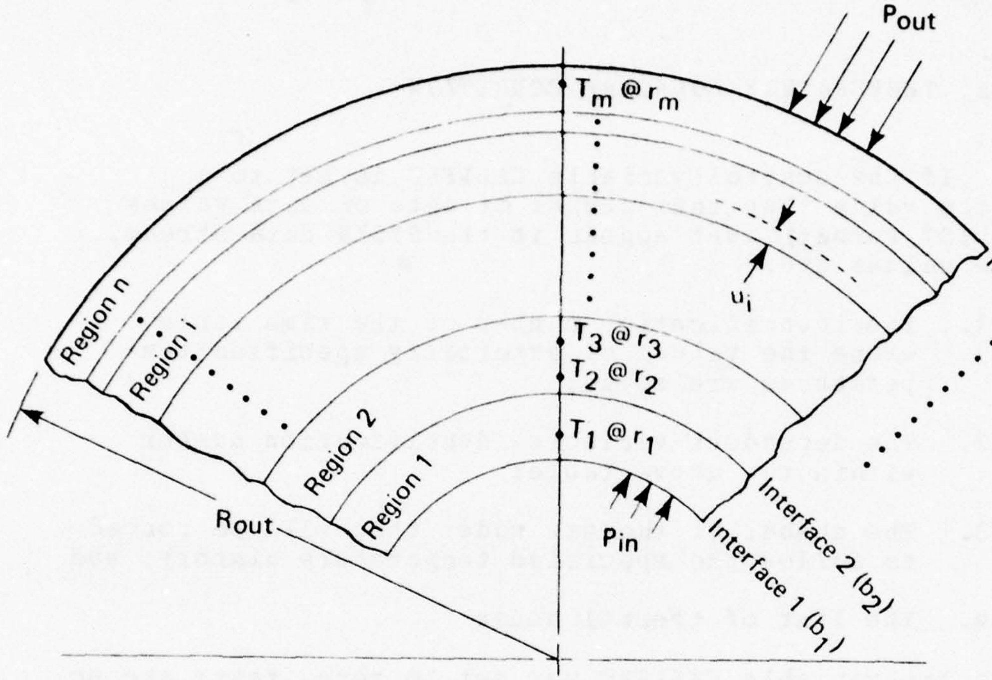
3. The number of thermal nodes that will be forced to follow the specified temperature history; and

4. The list of thermal nodes

Since the variable CALLFRC was set to zero, there are no data in the sample input. In the cases where temperature boundary conditions are input, the values are reformatted and printed on SYSPRINT for reference.

THERMAL STRESS PARAMETERS

If thermal stresses are to be calculated, then the control variable CALLSIG should be set to indicate the number of thermal stress cases that will be needed. For each of the CALLSIG number of cases the following data will be expected on the SYSIN file, in LIST format (for a definition of terms refer to Fig. 11 and Appendix K):



Notes:

- Total wall thickness $(b_{n+1} - b_1)$ is divided into n arbitrarily sized regions, creating n+1 interfaces.
- Temperatures are provided at m arbitrarily spaced radius values and are constant with respect to the axial and circumferential directions.
- Radial displacements from an initial isothermal state occur for each interface, u_i.
- Mechanical properties are assumed constant within regions at values that are temperature averaged with respect to the radial temperature variance.
- **Each region may have different mechnical properties**

Fig. 11 Thermal Stress Geometry and Nomenclature

Item Value

1. A file name for indicating where the node versus radius data is stored;

2. The number of positions through the wall at which temperatures will be specified;

3. The number of subdivisions through the wall for the finite difference solution to the thermal stress problem;

4. The pressure at the outside surface of the cylinder (psi);

5. The pressure at the inside surface of the cylinder (psi);

6. The temperature at which the cylinder will be assumed stress-free (°F);

7. The angle of incidence of the radar mainbeam (deg);

8. A flag for the type of boundary condition for the ends of the cylinder (1 for fully constrained ends; 0 for unconstrained ends);

9. A pseudo-node number used for saving the maximum tensile stress values versus time for plotting in another section of the program (the plotting is controlled by the variable PLOTS, whose value is set in the ctrol section; the value input here will be a thermal "node" number for the stress value and therefore must not be an actual thermal node number in the thermal network).

After these values have been read then the file named in 1 (above) will be read for the following data: 2 comment cards (160 characters) followed by tabular data with one of the following two types of entries:

a. In columns 40 to 55 a stress boundary card that gives a radial dimension (in.) for the interface between two adjacent stress regions, F-format;

or:

b. A thermal information card that gives the following:

(1) In columns 1 to 15, the radial position of the thermal node, (in.), F-format;

(2) In columns 16 to 25, the thermal network node number whose node center is at the corresponding radial position, F-format; and

(3) In columns 26 to 35, the mechanical property identification number (used for accessing the table of temperature dependent mechanical properties).

These data (items a or b) must not occur on the same card. Moreover, the separate cards are to be arranged in a manner that resembles the geometry being modeled; that is, beginning with the innermost radius (the inner surface) the data cards of type a or b are interleaved in increasing radial order, ending with the outer surface. Note that the inner and outer surface of the wall section being modeled are cards of type a and must be both the first and the last cards of the sequence. Thermal node and interface cards may have the same value of radius.

The EDIT-format input described above for the radius-temperature information may be circumvented if desired by an alternative, free-form input style through the setting of control variable SIGLIST. If SIGLIST is set to 1, then the radius-temperature-node information for each of the CALLSIG cases may be read in LIST format from the file named above. If SIGLIST is set to 1, then the following data will be read from the file named in 1 (above) in LIST format for each of the CALLSIG cases:

Item Value

1. For each position through the wall at which temperatures are known, a triplet (in increasing radial order) of:

   a. the thermal node number,

   b. the mechanical property code numbers, and

Item Value

c. the radius (in.).

2. For each radial subdivision interface:

a. the radial position (in.).

The sample problem has the control variable CALLSIG set to 30 and SIGIIST set to 0, so there are 30 data groups shown in the sample input (Appendix B). In all of the cases, the data tables of nodal positions are on the file SYSIN. For the first case, the control data indicate that the wall will have three nodal temperatures specified and the wall will be divided into only two subsections for the stress solution. The inner and outer surface pressures are both zero, the no-stress condition occurs at 59.3 °F, the radar incidence angle at this station is 65°, and the end condition is specified as being unconstrained. The last zero in the control data specification is a null input because the plot feature, controlled by the variable PLOTS, was turned off (PLOTS = 0).

The data tables for each case are shown in the sample input and they follow the formats as described here and show much repitition of data. It must be noted, however, that each thermal node number is different throughout all this input so each case is unique.

In the sample output there is a reprint of each of the geometry tables as read in, with sequential case numbers assigned.

BORESIGHT ERROR SLOPES

For calculating the boresight error slopes several parameters must be input for each case and they should occur at the next position in the SYSIN file. If the control variable CALLBSE is nonzero then that number of data groups must appear in the SYSIN file in the following order, LIST format:

1. A case number specifying which thermal stress case is to be used for this boresight error case

(it is often convenient to use a one-to-one correspondence between thermal stress and boresight error cases but this is not required);

2. The radar frequency to be used for the boresight calculation (Hz);

3. The phase center separation for the radar antenna (in.); and

4. A psuedo-node number for obtaining off-line CalComp plots of boresight error and electrical thickness change histories (if this value is zero, then no action will take place; if this value is nonzero, then this value and the next sequential value will be used to store boresight error and electrical thickness change, respectively, at each time point indicated for these calculations).

In the sample input data (directly after the last thermal stress geometry input) there are 30 triplets of data for the 30 boresight error cases to be made. The data show the one-to-one correspondence between boresight error case number and thermal stress case number. Also each calculation is done at a K-band frequency (30 GHz) with the same antenna aperture (3.89 in.). The sample output shows the data reprinted on the SYSPRINT file for reference.

VELOCITY LIMITS

The next section of data to be found on the SYSIN file concerns the specification of how the velocity limits will be calculated. In this section the selected parameters that will be potentially limiting are combined with the appropriate trajectories and design allowable properties so that the URLIM program can generate the velocity limits plots. For each plot that is called for, several identifying numbers must be supplied in a particular order so as to fully specify the limit plot. These numbers are to be on the SYSIN file and in LIST format:

1. The number of velocity versus time tables (tra-

jectories) that are to be plotted and

2. The number of capacitors that will be checked for melting on each of the trajectories.

Beginning at the first column of the next logical record:

3. A title card of 80 characters or less,

4. The thermal property material code number of the material for which the plot is being made,

5. The mechanical property identification number of the material for which the plot is being made,

6. For each of the number of trajectories specified in item 1 above, the following:

   a. The node numbers to be checked for melting (there must be as many entries here as specified in item 2 above for each trajectory),

   b. The thermal stress case number that will be examined for excessive thermal stress,

   c. The aerodynamic load case number that will be examined for excessive attachment stresses, and

   d. The trajectory identification number for this trajectory (i.e., the number of the time table to be used for the altitude and velocity versus time data).

Since the variable CAILLIM in the sample problem was set to 6, there are six groups of data in the sample input that follow the above format. The first one specifies that there are to be five trajectories examined and that on each of them 3 nodes will be examined for melting. The comment card tells what material and what flight path the limit plot is for. The thermal and mechanical material identification numbers are both 1 (and should therefore correspond to alumina). The nodes that will be subject to melting on the first trajectory are nodes No. 1, No. 2, and No. 3; the thermal stresses, aeroload, and trajectory data are those cases numbered 1. The

second trajectory has melt nodes No. 4, No. 5, and No. 6 and the stress and load data are to come from those cases numbered 2. The second time table is to be used for velocity versus time data. The rest of the data for the first limit plot follow in the same way for the other trajectories. The other five sets of data that specify the other limit plots follow immediately in the SYSIN file. All of this bookkeeping data for the limits plots is reformatted and printed on the output file. The sample output shows the six resulting tables, which can be very useful later when the analytical data are received.

CALCOMP PLOTS

Following the limits data there are two sections that deal with the analytical output of the program. The first of these deals with the CalComp plot facility and is controlled by the variable PLOTS. If PLOTS is set to any nonzero value, then immediately after the limits data on the SYSIN file the following items should be input in LIST format:

1. A file name identifying a file onto which will be written the information required to make the CalComp plots. There must be a JCL card describing this file included with the execution step of the URLIM run. An example of such a card would be:

```
//filename DD DSN=group.userid.xxx,
//        DISP=(NEW,CATLG),
//        UNIT=SAVE,SPACE=(3500,(10,10),RLSE)
```

   The plots are not made during the URLIM run, but the required data are saved. After the URLIM program execution, when the printed data have been inspected, a job may be run to plot selected variables as required (c.f. Appendix P for details of the execution of this secondary program).

2. Two 40-character strings (each enclosed in single quotes) to be used as titles in the plotting.

3. The number of times at which the data points are to be recorded.

4. The list of times at which the temperature data will be written on the file named in item 1 (above) (s).

If the number of times (item 3) is given as 1 and the single value input (item 4) is negative, then the temperatures will be written out to the file (item 1) at every time step of the URLIM program execution. If the number of items is 1 and the value input is positive then this value will be used successively as an increment of time from the starting time at which the values will be written out.

In the sample problem input there are no data for this option because the control variable PLOTS was set to zero. When data are input they are echoed directly to the SYSPRINT file for reference.

PRINTED RESULTS

During the execution of URLIM the various analytical subroutines can be called upon to print their results at intervals specified by a list of times. This facility is not selectable; i.e., the following data items must be next in the SYSIN data stream in LIST format.

1. The number of times at which data are to be printed and

2. The list of times for printout (s).

Note: If the value for item 1 is 1 and the single value for item 2 is negative then data will be printed at every time step during the execution (use with caution -- considerable output can be made this way). If the value for item 1 is 1 and the single value for item 2 is positive, then the item 2 value will be used as an increment in determining successive times from the initial time at which output will be printed. If the first value in the list of times to print (item 2) is 999 then the format for the printed temperatures will be

changed to a table that will include the node numbers, the temperatures, the total net conductances, and the net heat flows for each node.

The type of printed output can be controlled by the control variable MINPRNT. By default MINPRNT has the value 0 but it may be set equal to the values 1 or 2. These values have the following effects:

0 The printed output is directed in its entirety to the SYSPRINT file. The individual analytical routines print, in the order of their execution, detailed reports of the calculations involved.

1 The printed output is directed in its entirety to the SYSPRINT file. The individual routines, however, print only a much abbreviated (one-line) report of their calculations.

2 The analytical routines print their abbreviated output on the file SYSPRINT. The analytical routines also print their extended output reports to the file MAXPRNT, which must have a JCL card describing its format for the operating system.

The sample problem was run with MINPRNT set to 2; the JCL statements in Fig. 6 will show how the extensive output data file MAXPRNT was described. There is a facility available at APL for obtaining microfiche output from print files like MAXPRNT. This is accomplished by specifying "SYSOUT = Q" on the DD card. Appendix C contains the results of the minimum printing and Appendix D shows a sample of the extensive output that was written on microfiche.

There is a significance to the list of printout times in addition to that described so far: the list of times indicates how frequently the analytical routines for the limits calculations are executed. Specifically these routines are the ones that deal with thermal stress, boresight error, and aerodynamic load. Some consideration must therefore be given to how frequently these parameters will be evaluated during the flight simulation so that the respective parameter histories are not too coarse.

In the sample input 27 time points are specified

for printout ranging from 0 to 45 s. There is no direct indication in the sample output that these values were read; however, the output from the analytical routines is, of course, printed at the times that were specified.

FINAL INPUT

The last items that may be input prior to the flight simulation include the values listed in Table 1. Any other variable used in the URLIM main program (of which there are many) may be given values at this point in the SYSIN file by using the DATA format. These variables will have had values assigned to them during the earlier input but they may have their values changed in this section. This feature is mainly for the user with intimate knowlege of the URLIM code and is not generally usefull. However, whether or not any variables have their values changed, this section must end with a semicolon.

In the sample input there were no DATA-format entries so only a semicolon appears. The semicolon also appears on the sample output as the DATA-format entries would, if there were any.

At this point the input is complete and the program will execute according to the various data it has been given.

4. PROGRAM OUTPUT

In addition to the system-generated messages (JCL, data set allocations, and disposition) generic to the particular operating system, the output received from an URLIM run will be in two general parts. The first part will echo some of the input data so that it can be verified and later referred to by the user. The second part contains the results of the calculations by the various analytical subroutines and is printed as the time variable in the program advances. This second section of the output can be thought of as having two parts: the first is the normal output of the various program subroutines and the other part is a set of warning or error messages that may occur during execution. Appendix E lists these warning messages. Appendix C contains a part of the output from the sample problem that was printed on SYSPRINT and Appendix D contains a sample of the output that was written on microfiche from the file MAXPRNT. These sample results will be used to illustrate the general discussion that will follow the program's output.

SECTION I

This output is a partial echo of the input data and has been described in detail in Section 3 of this report. The following is a summary list of the types of data that may be printed in this section:

1. A direct echo of the control variable inputs;

2. The thermal property tables of the program materials (if THPROPS > 0);

3. The mechanical property tables (if any) of the program materials, (MCPROPS > 0);

4. The manually input thermal network information (if MANLIN > 0);

5. The cylindrical network data, if any (CALLCYL > 0);

6. The 2-dimensional Cartesian network data, if any (CALLTOD > 0);

7. The air property data, if used (CALLARO > 0);

8. The altitude tables, if used (CALLARO > 0);

9. The local flow ratio tables if used (CALLFLO > 0);

10. The missile and radome force coefficients, if used (CALLAFC > 0);

11. The time-dependent tables, if any (CALLTIM > 0);

12. The thermal stress geometry definitions, if any (CALLSIG > 0);

13. The limits directory tables, if any (CALLLIM > 0).

SECTION II

The analytical output is printed by each subroutine, in the order of execution, at every time interval specified by the input data for printing. The sample output for Section II is shown in Appendix C and is the 4-s output from the sample problem. When the output for any one time interval is complete, a line of asterisks is printed as a visual aid to separating the outputs of different times. The output information may contain the following data:

1. The current time in the program (s) (always on SYSPRINT).

2. The thermal capacitor temperatures (°F). Only the thermal nodes whose temperatures are different from the initial temperature are printed. Also, as a group of thermal nodes

reaches either a limit or the end of their trajectory, they will be dropped from the calculations. An appropriate warning message is printed when this happens (this output is always on SYSPRINT).

3. If aerodynamic heating is being used (CALLARO > 0) then the subroutine that calculates the local flow conditions and the surface temperature will print its data (according to the value of MINPRNT) next. The minimum output, which is always on SYSPRINT, is only one line and specifies: (1) the case number, (2) the Mach number, and (3) the iterations required to reach the solution to the surface energy balance. Appendix C shows this output for the sample problem. If the maximum output is called for, then more information will be printed. As shown in Appendix D, the extended output from the surface aerodynamic calculations includes: the block identification number; the freestream and local conditions of temperature, pressure, velocity, Mach number, and enthalpy; and data pertinent to the local flow calculation accuracy. For each surface node in the aero block the following is printed: the node number and its newly calculated temperature; the enthalpy-based heat transfer coefficient; the net convective heat flux to the hot surface (Btu/ft^2-s); the Reynolds number; the reference temperature, the adiabatic wall temperature and enthalpy; the heat to and from the wall via radiation (Btu/ft^2-s); the heat conducted from the surface into the structure (Btu/ft^2-s); the enthalpy of the stream at the wall temperature; the convergence parameters indicating the accuracy of the calculations; and the compressibility of the boundary layer gas at the reference condition.

4. If aerodynamic loads are being calculated (CALLLOD > 0) then the load routine will print its values at the current time. Appendix C shows samples of this output in abbreviated form with (1) the value of the maximum stress in the attachment area (2) the case number, and (3) the angle of attack of the missile. (If the angle of attack is followed by an asterisk

then the printed angle of attack is the maximum permissible and the missile is not capable of executing the required maneuver; otherwise the angle of attack is that which is required to pull the full maneuver acceleration.) Appendix D shows some examples of the extended output for the aero-load routine. In this output the case number is identified and the time is printed, the net normal and axial forces on the radome are printed (lbf), the net bending moment at the attachment is listed (ft-lbf), the windward and leeward stresses at the attachment point are shown (psi), the maximum allowable and the current angles of attack are given (deg), and the altitude (ft) and Mach number are listed.

5. If thermal stresses are calculated (CALLSIG > 0) then the thermal stress routine will print its abbreviated output (if required) in the format shown in Appendix C. This information is simply the case number and the maximum tensile stress in the wall. The extended output, if requested, contains a full description of the thermal stress analysis and is shown in the example in Appendix D. The output identifies the case number and the current time of the trajectory simulation. The maximum tensile stress is also given. A table is then printed that shows the stresses and temperatures as a function of radius along with the effective elastic modulus and the net radial expansion. Thermal node numbers (under the "INDEX" column) are also shown at their respective radii. The other temperatures given at other radii are interpolated temperatures. The hoop and axial stresses are printed at each external surface and at either side of each internal stress boundary. These stresses may vary at each interface because of the variance of the elastic modulus between adjacent regions. The radial stresses at the surface are simply the externally applied pressures. Within the wall the radial stresses exist across each boundary. The last line from the thermal stress routine gives the average axial expansion (in./in.) and also gives the net electrical thickness change in terms of the

insertion phase delay through the wall thickness.

6. If boresight error slopes are being calculated during the URLIM run, they will be printed on the SYSPRINT or MAXPRNT output files (as required) in the same format; i.e., the total output is simply the boresight error case number and the boresight error slope (degrees of error per degree of look angle).

7. If flight limits are being monitored and if a flight limit has been reached, a one-line message is printed out to the SYSPRINT file indicating what limit was exceeded and which limit case number is involved. Also the exact case number of the particular limiting parameter is listed along with the time of failure.

8. When all the output from a single time has been printed, a statement regarding the time step and the thermal node that is limiting the value of the time step is printed. The node is the "CRITICAL INDEX NO." and can be reviewed by the user to determine if thermal model changes need to be made to raise the time step.

9. When the URLIM program has finished the flight simulation aspect of its execution and if limits were monitored, then the velocity limits plots will be printed out on the SYSPRINT file.

10. After the limits plots, if any, a final message will be printed indicating the final time in the simulation and the total number of time steps taken during the simulation. This message will be the last output from a successful execution of the URLIM program.

The only other output will be operating system messages; the URLIM output is completed.

Mention has been made throughout this report of a sample problem and a library of subroutines used by URLIM in its calculations. The appendixes that follow contain the detailed descriptions of these parts of the URLIM code.

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Appendix A

DATA INPUT FORMATS

Data that are prepared for reading into the URLIM program will be character or stream type data. Most sections of URLIM will expect the input data files to have fixed length record formats (RECFM) of 80 characters (bytes) each. That is, the Data Control Block (DCB) of the Data Definitions (DD) statement should be

```
//filename DD DCB=(RECFM=FB,LRECL=80,BLKSIZE=x*80)
```

where the value x*80 represents a decimal integer that is some multiple of 80. The data on these cards will be in one of three basic formats according to what the program requires. These three formats are:

DATA wherein specific program variables are assigned values by name in the data stream; e.g.:

(variable name) = value

this format is free (i.e., is not dependent on column position on the card).

LIST wherein the data values are written in any decimal format in the specific order requested. This format is also column free but the values must be in the precise order required.

EDIT wherein the data values must be in specified formats in specified column fields on the cards. In EDIT directed input it will be required to use I-format, F-format, or E-format numerical representations; that is:

F-format is fixed decimal point and requires a decimal point to be used (e.g., -49.682);

I-format where integers are to be read (e.g., -287);

E-format where a floating point (scientific notation) number is used (e.g., -836.49E-6).

In this example the E-6 represents a power of 10 so that the number would be:

$-836.49 \times 10^{-6} = -0.00083649.$

In all of the above examples if a sign is not included, positive values will be assumed. Also, in the E-format there may be no spaces between + or - signs and the exponents (E).

Appendix B

SAMPLE INPUT

The following JCL and data cards are similar to the ones used to execute the sample problem referred to throughout this report. A few of the salient features include:

- The inclusion of a "//FLIDUMP DD " card so that the storage report may be printed thereon.

- The SYSIN file is a concatenated file; that is, it is made up of two data sets, the first being BBE. FRAZER.MHWDATA(SAMPLIN) and the other a brief card file. The contents of the BBE.FRAZER.MHWDATA(SAMPLIN) dataset are listed directly after the JCL (below).

- The MAXPRNT file is a regular print file (SYSOUT=A) but could just as easily have been microfiche (SYSOT=Q).

Contents of Dataset

BBE.FRAZER.MHWDATA(SAMPLIN)

```
CALLARO = 30
CALLLOD = 30
CALLSIG = 30
CALLBSE = 30
CALLCYL = 30
CALLFLO = 1
CALLLIM = 6
CALLTIM = 10
MANLIN = 1
MCPROPS = 3     MAXENTS = 18
THPROPS = 3
XCAPLIM = 185
#NODES = 185
AFCFILE = 'FORCOEF'
TINIT = 519
#ALPHA = 6     #MACH = 14
NETFILE = 'SYSIN'
MINSTEP = .019
STOPTIM = 4
MINRUN = 1
MINPRNT = 2
   ;
'SYSIN'   17   .01
```

THERMAL PROPS ALUMINA PREV. STUDY - TG 865

TEMP DEG R	RHC CP	CONDUCT'Y	EMISS	DIEL CONST
460.	45.9	23.	.780	9.6
560.	50.4	19.	.775	9.65
660.	54.0	16.	.770	9.7
760.	57.0	13.7	.765	9.75
860.	59.5	11.8	.760	9.80
960.	62.0	10.3	.747	9.85
1060.	63.7	9.0	.735	9.90
1260.	67.0	7.0	.700	10.03
1460.	69.5	5.7	.655	10.15
1660.	72.0	4.8	.610	10.25
2060.	76.2	3.7	.522	10.5
2460.	79.4	3.3	.457	10.75
2860.	82.6	3.4	.405	11.1
3260.	86.9	3.6	.360	11.4
3660.	91.7	4.0	.325	11.8
4060.	97.3	4.6	.295	12.3
4061.	97.3	4.6	.295	12.3

'SYSIN'   16   .C1C

THERMAL PROPS FUSED SILICA - TG 865

TEMP- DEG R	RHO CP	CONDUCT'Y	EMISS	DIEL CONST.
460.	19.2	.30	.84	3.35
660.	24.4	.31	.835	3.40
860.	27.6	.32	.822	3.43
1060.	30.0	.33	.792	3.45
1260.	31.3	.34	.745	3.46
1460.	32.4	.36	.687	3.47
1660.	33.4	.38	.622	3.48
1860.	34.2	.40	.572	3.49
2060.	34.9	.42	.532	3.50
2260.	35.4	.46	.510	3.52
2460.	35.8	.49	.520	3.56
2660.	36.6	.54	.555	3.62
2860.	37.2	.59	.610	3.75
3060.	38.0	.64	.670	3.85
3360.	39.6	.76	.730	4.15

3600.	41.1	.86	.690	4.40

'SYSIN' 18 .010

THERMAL PROPERTIES PYROCERAM - TG 865

TEMP DEG R	RHO CP	CONDUCT'Y	EMISS	DIEL CONST
460.	26.7	2.22	.850	5.65
560.	30.8	2.16	.846	5.65
660.	33.4	2.10	.842	5.67
760.	35.6	2.05	.837	5.67
860.	37.3	2.00	.832	5.68
960.	38.8	1.96	.822	5.69
1060.	39.9	1.93	.810	5.70
1260.	42.1	1.87	.765	5.71
1460.	43.7	1.82	.718	5.75
1660.	45.4	1.79	.698	5.79
1860.	47.0	1.76	.678	5.82
2060.	48.6	1.74	.654	5.88
2260.	50.2	1.73	.630	5.91
2460.	51.8	1.72	.617	6.01
2660.	53.5	1.71	.595	6.10
2860.	55.9	1.70	.587	6.13
2920.	56.7	1.70	.580	6.15
2930.	56.7	1.70	.580	6.15

'SYSIN' 11 18700

MECHANICAL PROPERTIES - ALUMINA TG 865

TEMP DEG F	MODULUS	POIS	EXPANSION
0.	50.0E6	.28	0.0E0
400.	49.5E6	.28	1.3E-3
800.	49.0E6	.28	2.9E-3
1200.	47.8E6	.28	4.8E-3
1600.	46.0E6	.28	7.0E-3
2000.	43.0E6	.29	9.2E-3
2400.	38.0E6	.30	11.4E-3
2800.	30.0E6	.30	13.8E-3
3200.	18.0E6	.30	16.2E-3
3600.	0.0E0	.30	18.6E-3
3610.	0.0E0	.30	18.7E-3

'SYSIN' 11 4000.0

MECHANICAL PROPERTIES FUSED SILICA - TG 865

TEMP DEG F	MODULUS	POIS	EXPANSION
0.	8.0E6	.15	0.0E0
400.	9.0E6	.16	0.18E-3
800.	10.0E6	.17	0.42E-3
1000.	10.0E6	.20	0.46E-3
1200.	10.1E6	.18	0.41E-3
1600.	9.9E6	.19	0.48E-3
2000.	8.5E6	.195	0.60E-3
2400.	6.0E6	.20	0.71E-3
2800.	1.5E6	.20	0.80E-3
3140.	0.0E0	.20	0.81E-3
3600.	0.0E0	.20	1.00E-3

'SYSIN' 18 22500.0

MECHANICAL PROPERTIES PYROCERAM TG 865

TEMP DEG F	MODULUS	POIS	EXPANSION
0.0	15.0E6	.25	0.0E0
100.	16.5E6	.25	0.1E-3
200.	16.5E6	.25	.5E-3
400.	16.5E6	.25	1.1E-3
600.	16.6E6	.25	1.6E-3
800.	16.7E6	.25	2.0E-3
1000.	16.8E6	.25	2.3E-3

1200.	17.0E6	.25	2.8E-3
1400.	16.9E6	.25	3.3E-3
1600.	16.8E6	.25	3.9E-3
1800.	15.0E6	.25	4.4E-3
2000.	14.3E6	.25	5.0E-3
2100.	13.0E6	.25	5.3E-3
2200.	11.5E6	.25	5.6E-3
2300.	8.5E6	.25	5.8E-3
2400.	5.5E6	.25	6.2E-3
2462.	0.0E6	.25	6.3E-3
2470.	0.0E6	.25	6.4E-3

1	1	.07182	2.216	1	2	0	0	1	0	5.4667E-3	2	360	1
1	1	.07182	2.216	1	5	0	0	1	0	5.4667E-3	2	360	1
1	1	.07182	2.216	1	8	0	0	1	0	5.4667E-3	2	360	1
1	1	.07182	2.216	1	11	0	0	1	0	5.4667E-3	2	360	1
1	1	.07182	2.216	1	14	0	0	1	0	5.4667E-3	2	360	1
1	1	.07182	2.216	2	22	0	0	1	0	9.2167E-3	6	360	1
1	1	.07182	2.216	2	29	0	0	1	0	9.2167E-3	6	360	1
1	1	.07182	2.216	2	36	0	0	1	0	9.2167E-3	6	360	1
1	1	.07182	2.216	2	43	0	0	1	0	9.2167E-3	6	360	1
1	1	.07182	2.216	2	50	0	0	1	0	9.2167E-3	6	360	1
1	1	.07182	2.216	3	62	0	0	1	0	7.04167E-3	4	360	1
1	1	.07182	2.216	3	67	0	0	1	0	7.04167E-3	4	360	1
1	1	.07182	2.216	3	72	0	0	1	0	7.04167E-3	4	360	1
1	1	.07182	2.216	3	77	0	0	1	0	7.04167E-3	4	360	1
1	1	.07182	2.216	3	82	0	0	1	0	7.04167E-3	4	360	1
1	1	.07182	2.216	1	102	0	0	1	0	5.4667E-3	2	360	1
1	1	.07182	2.216	1	105	0	0	1	0	5.4667E-3	2	360	1
1	1	.07182	2.216	1	108	0	0	1	0	5.4667E-3	2	360	1
1	1	.07182	2.216	1	111	0	0	1	0	5.4667E-3	2	360	1
1	1	.07182	2.216	1	114	0	0	1	0	5.4667E-3	2	360	1
1	1	.07182	2.216	2	122	0	0	1	0	9.2167E-3	6	360	1
1	1	.07182	2.216	2	129	0	0	1	0	9.2167E-3	6	360	1
1	1	.07182	2.216	2	136	0	0	1	0	9.2167E-3	6	360	1
1	1	.07182	2.216	2	143	0	0	1	0	9.2167E-3	6	360	1
1	1	.07182	2.216	2	150	0	0	1	0	9.2167E-3	6	360	1
1	1	.07182	2.216	3	162	0	0	1	0	7.04167E-3	4	360	1
1	1	.07182	2.216	3	167	0	0	1	0	7.04167E-3	4	360	1
1	1	.07182	2.216	3	172	0	0	1	0	7.04167E-3	4	360	1
1	1	.07182	2.216	3	177	0	0	1	0	7.04167E-3	4	360	1
1	1	.07182	2.216	3	182	0	0	1	0	7.04167E-3	4	360	1

GEOMETRY DEFINITIONS FOR SURFACE NODES

NODE	VOLUME	MATR'L	CONS	FIRST	A/L
1	0.0E0	1.	1.	2.	743.0E0
4	0.0E0	1.	1.	5.	743.0E0
7	0.0E0	1.	1.	8.	743.0E0
10	0.0E0	1.	1.	11.	743.0E0
13	0.0E0	1.	1.	14.	743.0E0
21	0.0E0	2.	1.	22.	1294.0E0
28	0.0E0	2.	1.	29.	1294.0E0
35	0.0E0	2.	1.	36.	1294.0E0
42	0.0E0	2.	1.	43.	1294.0E0
49	0.0E0	2.	1.	50.	1294.0E0
61	0.0E0	3.	1.	62.	1135.8E0
66	0.0E0	3.	1.	67.	1135.8E0
71	0.0E0	3.	1.	72.	1135.8E0
76	0.0E0	3.	1.	77.	1135.8E0
81	0.0E0	3.	1.	82.	1135.8E0
101	0.0E0	1.	1.	102.	743.0E0
104	0.0E0	1.	1.	105.	743.0E0

```
107          0.0E0       1.           1.        108.     743.0E0
110          0.0E0       1.           1.        111.     743.0E0
113          0.0E0       1.           1.        114.     743.0E0
121          0.0E0       2.           1.        122.    1294.0E0
128          0.0E0       2.           1.        129.    1294.0E0
135          0.0E0       2.           1.        136.    1294.0E0
142          0.0E0       2.           1.        143.    1294.0E0
149          0.0E0       2.           1.        150.    1294.0E0
161          0.0E0       3.           1.        162.    1135.8E0
166          0.0E0       3.           1.        167.    1135.8E0
171          0.0E0       3.           1.        172.    1135.8E0
176          0.0E0       3.           1.        177.    1135.8E0
181          0.0E0       3.           1.        182.    1135.8E0

  'AIR' 7   28
  'ATMOS'   30
 1   1   1   1   1.0E6   1   2   1   10     1     2    1  .13333   1
 1   1   2   1   1.0E6   1   2   1   10     4     5    1  .13333   1
 1   1   3   1   1.0E6   1   2   1   10     7     8    1  .13333   1
 1   1   4   1   1.0E6   1   2   1   10    10    11    1  .13333   1
 1   1   5   1   1.0E6   1   2   1   10    13    14    1  .13333   1
 1   1   1   1   1.0E6   1   2   1   10    21    22    1  .13333   1
 1   1   2   1   1.0E6   1   2   1   10    28    29    1  .13333   1
 1   1   3   1   1.0E6   1   2   1   10    35    36    1  .13333   1
 1   1   4   1   1.0E6   1   2   1   10    42    43    1  .13333   1
 1   1   5   1   1.0E6   1   2   1   10    49    50    1  .13333   1
 1   1   1   1   1.0E6   1   2   1   10    61    62    1  .13333   1
 1   1   2   1   1.0E6   1   2   1   10    66    67    1  .13333   1
 1   1   3   1   1.0E6   1   2   1   10    71    72    1  .13333   1
 1   1   4   1   1.0E6   1   2   1   10    76    77    1  .13333   1
 1   1   5   1   1.0E6   1   2   1   10    81    82    1  .13333   1
 1   1   6   1   1.0E6   1   2   1   10   101   102    1  .13333   1
 1   1   7   1   1.0E6   1   2   1   10   104   105    1  .13333   1
 1   1   8   1   1.0E6   1   2   1   10   107   108    1  .13333   1
 1   1   9   1   1.0E6   1   2   1   10   110   111    1  .13333   1
 1   1   10  1   1.0E6   1   2   1   10   113   114    1  .13333   1
 1   1   6   1   1.0E6   1   2   1   10   121   122    1  .13333   1
 1   1   7   1   1.0E6   1   2   1   10   128   129    1  .13333   1
 1   1   8   1   1.0E6   1   2   1   10   135   136    1  .13333   1
 1   1   9   1   1.0E6   1   2   1   10   142   143    1  .13333   1
 1   1   10  1   1.0E6   1   2   1   10   149   150    1  .13333   1
 1   1   6   1   1.0E6   1   2   1   10   161   162    1  .13333   1
 1   1   7   1   1.0E6   1   2   1   10   166   167    1  .13333   1
 1   1   8   1   1.0E6   1   2   1   10   171   172    1  .13333   1
 1   1   9   1   1.0E6   1   2   1   10   176   177    1  .13333   1
 1   1   10  1   1.0E6   1   2   1   10   181   182    1  .13333   1
'FLORATS'   17
    28.3     6.75     .0656     110    248    1500     966    0     650   1 0
    28.3     6.75     .0656     110    248    1500     966    0     650   2 0
    28.3     6.75     .0656     110    248    1500     966    0     650   3 0
    28.3     6.75     .0656     110    248    1500     966    0     650   4 0
    28.3     6.75     .0656     110    248    1500     966    0     650   5 0
    28.3     6.75     .1106     110    120    1500     966    0     650   1 0
    28.3     6.75     .1106     110    120    1500     966    0     650   2 0
    28.3     6.75     .1106     110    120    1500     966    0     650   3 0
    28.3     6.75     .1106     110    120    1500     966    0     650   4 0
    28.3     6.75     .1106     110    120    1500     966    0     650   5 0
    28.3     6.75     .0845     110    162    1500     966    0     650   1 0
    28.3     6.75     .0845     110    162    1500     966    0     650   2 0
    28.3     6.75     .0845     110    162    1500     966    0     650   3 0
```

```
  28.3     6.75     .0845     110      162     1500       966      0      650  4 0
  28.3     6.75     .0845     110      162     1500       966      0      650  5 0
  28.3     6.75     .0656     110      248     1500       966      0      650  6 0
  28.3     6.75     .0656     110      248     1500       966      0      650  7 0
  28.3     6.75     .0656     110      248     1500       966      0      650  8 0
  28.3     6.75     .0656     110      248     1500       966      0      650  9 0
  28.3     6.75     .0656     110      248     1500       966      0      650 10 0
  28.3     6.75     .1106     110      120     1500       966      0      650  6 0
  28.3     6.75     .1106     110      120     1500       966      0      650  7 0
  28.3     6.75     .1106     110      120     1500       966      0      650  8 0
  28.3     6.75     .1106     110      120     1500       966      0      650  9 0
  28.3     6.75     .1106     110      120     1500       966      0      650 10 0
  28.3     6.75     .0845     110      162     1500       966      0      650  6 0
  28.3     6.75     .0845     110      162     1500       966      0      650  7 0
  28.3     6.75     .0845     110      162     1500       966      0      650  8 0
  28.3     6.75     .0845     110      162     1500       966      0      650  9 0
  28.3     6.75     .0845     110      162     1500       966      0      650 10 0
'SYSIN'   2
          TIME TABLE FOR V1 TRAJ @ QE = 20
 TIME        ALT          VELOCITY   QRAD IN    MAX ALPHA
  0.          0.            1.                  20.
 45.      92345.440  12000.                     20.
'SYSIN'   2
          TIME TABLE FOR V2 TRAJ @ QE = 20
 TIME        ALT          VELOCITY   QRAD IN    MAX ALPHA
  0.          0.            1.                  20.
 30.      61563.6     12000.                    20.
'SYSIN'   2
          TIME TABLE FOR V3 TRAJ @ QE = 20
 TIME        ALT          VELOCITY   QRAD IN    MAX ALPHA
  0.          0.            1.                  20.
 20.      41042.4     12000.                    20.
'SYSIN'   2
          TIME TABLE FOR V4 TRAJ @ QE = 20
 TIME        ALT          VELOCITY   QRAD IN    MAX ALPHA
  0.          0.            1.                  20.
 10.      20521.2     12000.                    20.
'SYSIN'   2
          TIME TABLE FOR V5 TRAJ @ QE = 20
 TIME        ALT          VELOCITY   QRAD IN    MAX ALPHA
  0.          0.            1.                  20.
  5.      10260.0     12000.                    20.
'SYSIN'   3
          TIME TABLE FOR V1 TRAJ @ QE = 80
 TIME        ALT          VELOCITY   QRAD IN    MAX ALPHA
  0.          0.            1.                  20.
 27.59    100000.     7358.5                    20.
 45.      100000.     12000.                    20.
'SYSIN'   3
          TIME TABLE FOR V2 TRAJ @ QE = 80
 TIME        ALT          VELOCITY   QRAD IN    MAX ALPHA
  0.          0.            1.                  20.
 [illegible] 100000.   9012.                    20.
 [illegible] 100000.  12000.                    20.
'SYSIN'   3
          TIME TABLE FOR V3 TRAJ @ QE = 80
 TIME        ALT          VELOCITY   QRAD IN    MAX ALPHA
  0.          0.            1.                  20.
 [illegible] [illegible] 11028.5                20.
 [illegible] [illegible] 12000.                 20.
```

```
'SYSIN'  2
          TIME TABLE FOR V4 TRAJ @ QF = 80
 TIME        ALT        VELOCITY  QRAD IN   MAX ALPHA
  0.         0.          1.                 20.
 10.    59088.     12000.                   20.
'SYSIN'  2
          TIME TABLE FOR V5 TRAJ @ QF = 80
 TIME        ALT        VELOCITY  QRAD IN   MAX ALPHA
  0.         0.          1.                 20.
 5.     29544.0    12000.                   20.
'SYSIN'   3    2    0    0    59.3    65    0    0
    THERMAL STRESS GEOMETRY DATA FOR   LIMIT  STUDY
  RADIUS          NODE    MAT CODE          INTERFACE RADIUS
                                             .79624
 .79624            3.          1.
                                             .82904
 .84544            2.          1.
 .86184            1.          1.
                                             .86184
'SYSIN'   3    2    0    0    59.3    65    0    0

                                             .79624
 .79624            6.          1.
                                             .82904
 .84544            5.          1.
 .86184            4.          1.
                                             .86184
'SYSIN'   3    2    0    0    59.3    65    0    0

                                             .79624
 .79624            9.          1.
                                             .82904
 .84544            8.          1.
 .86184            7.          1.
                                             .86184
'SYSIN'   3    2    0    0    59.3    65    0    0

                                             .79624
 .79624           12.          1.
                                             .82904
 .84544           11.          1.
 .86184           10.          1.
                                             .86184
'SYSIN'   3    2    0    0    59.3    65    0    0

                                             .79624
 .79624           15.          1.
                                             .82904
 .84544           14.          1.
 .86184           13.          1.
                                             .86184
  'SYSIN'   7    4    0    0    59.3    65    0    0

                                             .75124
 .75124           27.          2.
```

```
.77889        26.        2.
                                   .7881
.79723        25.        2.
.81575        24.        2.
                                   .82496
.83418        23.        2.
                                   .84339
.85261        22.        2.
.86184        21.        2.
                                   .86184
  'SYSIN'   7     4     0     0     59.3   65     0     0
                                   .75124
.75124        34.        2.
.77889        33.        2.
                                   .7881
.79723        32.        2.
.81575        31.        2.
                                   .82496
.83418        30.        2.
                                   .84339
.85261        29.        2.
.86184        28.        2.
                                   .86184
  'SYSIN'   7     4     0     0     59.3   65     0     0
                                   .75124
.75124        41.        2.
.77889        40.        2.
                                   .7881
.79723        39.        2.
.81575        38.        2.
                                   .82496
.83418        37.        2.
                                   .84339
.85261        36.        2.
.86184        35.        2.
                                   .86184
  'SYSIN'   7     4     0     0     59.3   65     0     0
                                   .75124
.75124        48.        2.
.77889        47.        2.
                                   .7881
.79723        46.        2.
.81575        45.        2.
                                   .82496
.83418        44.        2.
                                   .84339
.85261        43.        2.
.86184        42.        2.
                                   .86184
  'SYSIN'   7     4     0     0     59.3   65     0     0
                                   .75124
.75124        55.        2.
```

```
.77889          54.         2.
                                        .7881
.79723          53.         2.
.81575          52.         2.
                                        .82496
.83418          51.         2.
                                        .84339
.85261          50.         2.
.86184          49.         2.
                                        .86184
  'SYSIN'   5    4     0     0     59.3    65     0     0

                                        .77784
.77784          65.         3.
                                        .79884
.80934          64.         3.
                                        .81984
.83034          63.         3.
                                        .84084
.85134          62.         3.
.86184          61.         3.
                                        .86184
  'SYSIN'   5    4     0     0     59.3    65     0     0

                                        .77784
.77784          70.         3.
                                        .79884
.80934          69.         3.
                                        .81984
.83034          68.         3.
                                        .84084
.85134          67.         3.
.86184          66.         3.
                                        .86184
  'SYSIN'   5    4     0     0     59.3    65     0     0

                                        .77784
.77784          75.         3.
                                        .79884
.80934          74.         3.
                                        .81984
.83034          73.         3.
                                        .84084
.85134          72.         3.
.86184          71.         3.
                                        .86184
  'SYSIN'   5    4     0     0     59.3    65     0     0

                                        .77784
.77784          80.         3.
                                        .79884
.80934          79.         3.
                                        .81984
.83034          78.         3.
                                        .84084
.85134          77.         3.
```

```
.86184         76.         3.
                                             .86184
   'SYSIN'   5     4      0      0      59.3    65      0      0

                                             .77784
 .77784          85.         3.
                                             .79884
 .80934          84.         3.
                                             .81984
 .83034          83.         3.
                                             .84084
 .85134          82.         3.
 .86184          81.         3.
                                             .86184
'SYSIN'     3      2      0      0      59.3     65      0      0

                                             .79624
  .79624         103.          1.
                                             .82904
  .84544         102.          1.
  .86184         101.          1.
                                             .86184
'SYSIN'     3      2      0      0      59.3     65      0      0

                                             .79624
  .79624         106.          1.
                                             .82904
  .84544         105.          1.
  .86184         104.          1.
                                             .86184
'SYSIN'     3      2      0      0      59.3     65      0      0

                                             .79624
  .79624         109.          1.
                                             .82904
  .84544         108.          1.
  .86184         107.          1.
                                             .86184
'SYSIN'     3      2      0      0      59.3     65      0      0

                                             .79624
  .79624         112.          1.
                                             .82904
  .84544         111.          1.
  .86184         110.          1.
                                             .86184
'SYSIN'     3      2      0      0      59.3     65      0      0

                                             .79624
  .79624         115.          1.
                                             .82904
  .84544         114.          1.
  .86184         113.          1.
                                             .86184
```

```
 'SYSIN'   7    4     0     0     59.3   65     0     0

                                      .75124
.75124        127.        2.
.77889        126.        2.
                                      .7881
.79723        125.        2.
.81575        124.        2.
                                      .82496
.83418        123.        2.
                                      .84339
.85261        122.        2.
.86184        121.        2.
                                      .86184
 'SYSIN'   7    4     0     0     59.3   65     0     0

                                      .75124
.75124        134.        2.
.77889        133.        2.
                                      .7881
.79723        132.        2.
.81575        131.        2.
                                      .82496
.83418        130.        2.
                                      .84339
.85261        129.        2.
.86184        128.        2.
                                      .86184
 'SYSIN'   7    4     0     0     59.3   65     0     0

                                      .75124
.75124        141.        2.
.77889        140.        2.
                                      .7881
.79723        139.        2.
.81575        138.        2.
                                      .82496
.83418        137.        2.
                                      .84339
.85261        136.        2.
.86184        135.        2.
                                      .86184
 'SYSIN'   7    4     0     0     59.3   65     0     0

                                      .75124
.75124        148.        2.
.77889        147.        2.
                                      .7881
.79723        146.        2.
.81575        145.        2.
                                      .82496
.83418        144.        2.
                                      .84339
.85261        143.        2.
.86184        142.        2.
                                      .86184
```

```
  'SYSIN'   7    4     0     0     59.3   65     0     0

                                        .75124
.75124          155.         2.
.77889          154.         2.
                                        .7881
.79723          153.         2.
.81575          152.         2.
                                        .82496
.83418          151.         2.
                                        .84339
.85261          150.         2.
.86184          149.         2.
                                        .86184
  'SYSIN'   5    4     0     0     59.3   65     0     0

                                        .77784
.77784          165.         3.
                                        .79884
.80934          164.         3.
                                        .81984
.83034          163.         3.
                                        .84084
.85134          162.         3.
.86184          161.         3.
                                        .86184
  'SYSIN'   5    4     0     0     59.3   65     0     0

                                        .77784
.77784          170.         3.
                                        .79884
.80934          169.         3.
                                        .81984
.83034          168.         3.
                                        .84084
.85134          167.         3.
.86184          166.         3.
                                        .86184
  'SYSIN'   5    4     0     0     59.3   65     0     0

                                        .77784
.77784          175.         3.
                                        .79884
.80934          174.         3.
                                        .81984
.83034           173.        3.
                                        .84084
.85134          172.         3.
.86184          171.         3.
                                        .86184
  'SYSIN'   5    4     0     0     59.3   65     0     0

                                        .77784
.77784          180.         3.
                                        .79884
```

```
.80934        179.        3.
                                    .81984
.83034        178.        3.
                                    .84C84
.85134        177.        3.
.86184        176.        3.
                                    .86184
  'SYSIN'   5    4    0    0    59.3   65    0    0

                                    .77784
.77784        185.        3.
                                    .79884
.80934        184.        3.
                                    .81984
.83034        183.        3.
                                    .84084
.85134        182.        3.
.86184        181.        3.
                                    .86184
 1   3E10   3.89  0  2  3E10  3.89  0   3  3E10  3.89  0   4 3E10 3.89 0
 5   3E10   3.89  0  6  3E10  3.89  0   7  3E10  3.89  0   8 3E10 3.89 0
 9   3E10   3.89  0 10  3E10  3.89  0  11  3E10  3.89  0  12 3E10 3.89 0
13   3E10   3.89  0 14  3E10  3.89  0  15  3E10  3.89  0  16 3E10 3.89 0
17   3E10   3.89  0 18  3E10  3.89  0  19  3E10  3.89  0  20 3E10 3.89 0
21   3E10   3.89  0 22  3E10  3.89  0  23  3E10  3.89  0  24 3E10 3.89 0
25   3E10   3.89  0 26  3E10  3.89  0  27  3E10  3.89  0  28 3E10 3.89 0
29   3E10   3.89  0 30  3E10  3.89  0
 5    3
          ALUMINA AT 20 DEGREE LAUNCH ANGLE
          1 1   1   2   3     1   1   1
                4   5   6     2   2   2
                7   8   9     3   3   3
               10  11  12     4   4   4
               13  14  15     5   5   5
 5    7
        FUSED SILICA AT 20 DEGREE LAUNCH ANGLE
         2 2   21   22   23   24   25   26   27     6   6   1
               28   29   30   31   32   33   34    7 7    2
               35   36   37   38   39   40   41     8   8   3
               42   43   44   45   46   47   48    9 9          4
               49   50   51   52   53   54   55   10  10      5
 5    5
       PYROCERAM AT 20 DEGREE LAUNCH ANGLF
                3    3    61   62   63   64   65     11   11       1
                          66   67   68   69   70    12   12   2
                             71   72   73   74   75    13   13      3
                          76   77   78   79   80       14   14   4
                          81   82   83   84   85       15   15   5
  5    3
          ALUMINA AT 80 DEGRFE LAUNCH ANGLE
                1    1   101   102   103    16  16     6
                         104   105   106    17  17        7
                        107  108  109    18   18     8
                         110   111   112    19  19            9
                         113   114   115    20  20   10
     5    7
        FUSED SILICA AT 80 DEGREE LAUNCH ANGLE
         2 2   121  122  123  124  125  126  127     21  21     6
               128  129  130  131  132  133  134    22   22      7
```

```
                 135   136   137   138   139   140   141    23    23    8
                142   143   144   145   146   147   148    24  24    9
                149   150   151   152   153   154   155    25  25    10
5    5
   PYROCERAM AT 80 DEGREE LAUNCH ANGLE
             3     3    161   162  163  164  165     26    26    6
                        166   167  168  169  170    27    27      7
                         171   172   173   174   175    28   28   8
                        176   177  178  179   180    29    29       9
                         181    182    183    184   185    30    30    10
   19
   4 5 6 8 10 12 15 18 20 22 25 27 30 32 35 37 40 42 45
```

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
LAUREL, MARYLAND

Appendix C

SAMPLE OUTPUT

The listing included herein was produced during the sample problem execution and was written on file SYS-PRINT. It contains, in addition to the system generated JCL and disposition lines the partial echo of the input data and a sample of the minimum print output.

```
CALLARO = 30
CALLLOD = 30
CALLSIG = 30
CALLBSE = 30
CALLCYL = 30
CALLPLO = 1
CALLLIM = 6
CALLTIM = 10
MANLIN = 1
MCPROPS = 3     MAXENTS = 18
THPROPS = 3
XCAPLIM = 185
#NODES = 185
APCFILE = 'FCRCOEF'
TINIT = 519
#ALPHA = 6     #MACH = 14
NETFILE = 'SYSIN'
MINSTEP = .019
STOPTIM = 4
MINRUN = 1
MINPRNT = 2
     ;
```

THE DATA FOR READRK STATEMENT # 1:
THERMAL PROPS ALUMINA PREV. STUDY - TG 865

TEMP DEG R	RHO CP	CONDUCT'Y	EMISS	DIEL CONST	
460.000	45.900	23.000	0.780	9.000	0.00600
560.000	50.400	19.000	0.775	9.000	0.06500
660.000	54.000	16.000	0.770	9.000	0.00700
760.000	57.000	13.700	0.765	9.000	0.07500
860.000	59.500	11.800	0.760	9.000	0.08000
960.000	62.000	10.300	0.747	9.000	0.08500
1060.000	63.700	9.000	0.735	9.000	0.09000
1260.000	67.000	7.000	0.700	10.000	0.00300
1460.000	69.500	5.700	0.655	10.000	0.01500
1660.000	72.000	4.800	0.610	10.000	0.02500
2060.000	76.200	3.700	0.522	10.000	0.00500
2460.000	79.400	3.300	0.457	10.000	0.07500
2860.000	82.600	3.400	0.405	11.000	0.00100
3260.000	86.900	3.600	0.360	11.000	0.00400
3660.000	91.700	4.000	0.325	11.000	0.00800
4060.000	97.300	4.600	0.295	12.000	0.00300
4061.000	97.300	4.600	0.295	12.000	0.00300

THE MAXIMUM BORESIGHT ERROR SLOPE ASSOCIATED WITH THIS MATERIAL IS 1.000E-02

THE DATA FOR READRK STATEMENT # 2:
THERMAL PROPS FUSED SILICA - TG 865

TEMP- DEG R	RHO CP	CONDUCT'Y	EMISS	DIEL CONST.	
460.000	19.200	0.300	0.840	3.350	0.00000
660.000	24.400	0.310	0.835	3.400	0.00000
860.000	27.600	0.320	0.822	3.430	0.00000
1060.000	30.000	0.330	0.792	3.450	0.00000
1260.000	31.300	0.340	0.745	3.460	0.00000
1460.000	32.400	0.360	0.687	3.470	0.00000
1660.000	33.400	0.380	0.622	3.480	0.00000
1860.000	34.200	0.400	0.572	3.490	0.00000

2060.000	34.800	0.420	0.532	3.500	0.00000
2260.000	35.400	0.460	0.510	3.520	0.00000
2460.000	35.800	0.490	0.520	3.560	0.00000
2660.000	36.600	0.540	0.555	3.620	0.00000
2860.000	37.200	0.590	0.610	3.750	0.00000
3060.000	38.000	0.640	0.670	3.850	0.00000
3360.000	39.600	0.760	0.730	4.150	0.00000
3600.000	41.100	0.860	0.690	4.400	0.00000

THE MAXIMUM BORESIGHT ERROR SLOPE ASSOCIATED WITH THIS MATERIAL IS 1.000E-02

THE DATA FOR READER STATEMENT # 3:
THERMAL PROPERTIES PYROCERAM - TG 865

TEMP DEG R	RHO CP	CONDUCT'Y	EMISS	DIEL CONST	
460.000	26.700	2.220	0.850	5.650	0.00000
560.000	30.800	2.160	0.846	5.650	0.00000
660.000	33.400	2.100	0.842	5.670	0.00000
760.000	35.600	2.050	0.837	5.670	0.00000
860.000	37.300	2.000	0.832	5.680	0.00000
960.000	38.800	1.960	0.822	5.690	0.00000
1060.000	39.900	1.930	0.810	5.700	0.00000
1260.000	42.100	1.870	0.765	5.710	0.00000
1460.000	43.700	1.820	0.718	5.750	0.00000
1660.000	45.400	1.790	0.698	5.790	0.00000
1860.000	47.000	1.760	0.678	5.820	0.00000
2060.000	48.600	1.740	0.654	5.880	0.00000
2260.000	50.200	1.730	0.630	5.910	0.00000
2460.000	51.800	1.720	0.617	6.010	0.00000
2660.000	53.500	1.710	0.595	6.100	0.00000
2860.000	55.900	1.700	0.587	6.130	0.00000
2920.000	56.700	1.700	0.580	6.150	0.00000
2930.000	56.700	1.700	0.580	6.150	0.00000

THE MAXIMUM BORESIGHT ERROR SLOPE ASSOCIATED WITH THIS MATERIAL IS 1.000E-02

THE DATA FOR READER STATEMENT # 1:
MECHANICAL PROPERTIES - ALUMINA TG 865

TEMP DEG F	MODULUS	POIS	EXPANSION	** MODULUS FUNCTION** E/(1-NU)
0.000	5.000E+07	0.280	0.000E+00	6.944E+07
400.000	4.950E+07	0.280	1.300E-03	6.875E+07
800.000	4.900E+07	0.280	2.900E-03	6.806E+07
1200.000	4.780E+07	0.280	4.800E-03	6.639E+07
1600.000	4.600E+07	0.280	7.000E-03	6.389E+07
2000.000	4.300E+07	0.290	9.200E-03	6.056E+07
2400.000	3.800E+07	0.300	1.140E-02	5.429E+07
2800.000	3.000E+07	0.300	1.380E-02	4.286E+07
3200.000	1.800E+07	0.300	1.620E-02	2.571E+07
3600.000	0.000E+00	0.300	1.860E-02	0.000E+00
3610.000	0.000E+00	0.300	1.870E-02	0.000E+00

THE MAXIMUM ALLOWABLE TENSILE STRESS FOR THIS MATERIAL IS 1.870E+04

THE DATA FOR READER STATEMENT # 2:
MECHANICAL PROPERTIES FUSED SILICA - TG 865

TEMP DEG F	MODULUS	POIS	EXPANSION

				** MODULUS FUNCTION** E/(1-NU)
0.000	8.000E+06	0.150	0.000E+00	9.412E+06
400.000	9.000E+06	0.160	1.800E-04	1.071E+07
800.000	1.000E+07	0.170	4.200E-04	1.205E+07
1000.000	1.000E+07	0.200	4.600E-04	1.250E+07
1200.000	1.010E+07	0.180	4.100E-04	1.232E+07
1600.000	9.900E+06	0.190	4.800E-04	1.222E+07
2000.000	8.500E+06	0.195	6.000E-04	1.056E+07
2400.000	6.000E+06	0.200	7.100E-04	7.500E+06
2800.000	1.500E+06	0.200	8.000E-04	1.875E+06
3140.000	0.000E+00	0.200	8.100E-04	0.000E+00
3600.000	0.000E+00	0.200	1.000E-03	0.000E+00

THE MAXIMUM ALLOWABLE TENSILE STRESS FOR THIS MATERIAL IS 4.000E+03

THE DATA FOR READFB STATEMENT # 3;
MECHANICAL PROPERTIES PYROCERAM TG 865

TEMP DEG F	MODULUS	POIS	EXPANSION	** MODULUS FUNCTION** E/(1-NU)
0.000	1.500E+07	0.250	0.000E+00	2.000E+07
100.000	1.650E+07	0.250	1.000E-04	2.200E+07
200.000	1.650E+07	0.250	5.000E-04	2.200E+07
400.000	1.650E+07	0.250	1.100E-03	2.200E+07
600.000	1.660E+07	0.250	1.600E-03	2.213E+07
800.000	1.670E+07	0.250	2.000E-03	2.227E+07
1000.000	1.680E+07	0.250	2.300E-03	2.240E+07
1200.000	1.700E+07	0.250	2.800E-03	2.267E+07
1400.000	1.690E+07	0.250	3.300E-03	2.253E+07
1600.000	1.680E+07	0.250	3.900E-03	2.240E+07
1800.000	1.500E+07	0.250	4.400E-03	2.000E+07
2000.000	1.430E+07	0.250	5.000E-03	1.907E+07
2100.000	1.300E+07	0.250	5.300E-03	1.733E+07
2200.000	1.150E+07	0.250	5.600E-03	1.533E+07
2300.000	8.500E+06	0.250	5.800E-03	1.133E+07
2400.000	5.500E+06	0.250	6.200E-03	7.333E+06
2462.000	0.000E+00	0.250	6.300E-03	0.000E+00
2470.000	0.000E+00	0.250	6.400E-03	0.000E+00

THE MAXIMUM ALLOWABLE TENSILE STRESS FOR THIS MATERIAL IS 2.250E+04

CYL2I REGION 1

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
2	2.6813E-03	1	1	3	2.3223E+02	0	0.0000E+00
3	2.5773E-03	1	0	0	0.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
2 @ 2.7333E-03 1 @ 6.2832E+00

OUTER RADIUS = 7.182E-02, DEPTH = 2.216E+00, SIDES = 0 0 1 0

CYL2I REGION 2

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2

```
     5       2.6813E-03     1          1          6    2.3223E+02        0      0.0000E+00
     6       2.5773E-03     1          0          C    0.0000E+00        0      0.0000E+00

 GRID DIMENSIONS (FEET & DEGS):
          RADIAL          CIRCUMFERENTIAI
   2 @   2.7333E-03     1 @   6.2832E+00

 OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0

                                 CYL2I REGION  3

  CAPACITOR      VOLUME  PROPCODE   NUM CONS   1ST CON     A/L 1        2ND CON     A/L 2
     8       2.6813E-03     1          1          9    2.3223E+02        0      0.0000E+00
     9       2.5773E-03     1          0          C    C.0000E+00        0      0.0000E+00

 GRID DIMENSIONS (FEET & DEGS):
          RADIAL          CIRCUMFERENTIAI
   2 @   2.7333E-03     1 @   6.2832E+00

 OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+0C, SIDES =   0  0  1  0

                                 CYL2I REGION  4

  CAPACITOR      VOLUME  PROPCODE   NUM CONS   1ST CON     A/L 1        2ND CON     A/L 2
    11       2.6813E-03     1          1         12    2.3223E+02        0      0.0000E+00
    12       2.5773E-03     1          0          C    0.0000E+00        0      0.0000E+00

 GRID DIMENSIONS (FEET & DEGS):
          RADIAL          CIRCUMFERENTIAI
   2 @   2.7333E-03     1 @   6.2832E+00

 CUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0

                                 CYL2I REGION  5

  CAPACITOR      VOLUME  PROPCODE   NUM CCNS   1ST CON     A/L 1        2ND CON     A/L 2
    14       2.6813E-03     1          1         15    2.3223E+02        0      0.0000E+00
    15       2.5773E-03     1          0          C    C.0000E+00        0      0.0000E+C0

 GRID DIMENSIONS (FEET & DEGS):
          RADIAL          CIRCUMFERENTIAI
   2 @   2.7333E-03     1 @   6.2832E+00

 OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0

                                 CYL2I REGION  6

  CAPACITOR      VOLUME  PROPCODE   NUM CONS   1ST CON     A/L 1        2ND CON     A/L 2
    22       1.5197E-03     2          1         23    6.3703E+02        0      0.0000E+00
    23       1.4868E-03     2          1         24    6.2312E+02        0      0.0000E+00
    24       1.4540E-03     2          1         25    6.0919E+02        0      0.0000E+00
    25       1.4211E-03     2          1         26    5.9526E+02        0      0.0000E+00
    26       1.3883E-03     2          1         27    3.8521E+02        0      0.0000E+00
    27       1.3554E-03     2          0          0    0.0000E+00        0      0.0000E+00

 GRID DIMENSIONS (FEET & DEGS):
```

AD-A057 459 JOHNS HOPKINS UNIV LAUREL MD APPLIED PHYSICS LAB F/G 17/9
URLIM - A UNIFIED RADOME LIMITATIONS COMPUTER PROGRAM. VOLUME 2--ETC(U)
APR 78 R K FRAZER N00017-72-C-4401
UNCLASSIFIED APL/JHU/TG-1293B NL

2 OF 3
ADA
057459

```
       RADIAL          CIRCUMFERENTIAL
  6 @  1.5361E-03       1 @  6.2832E+00

OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0

                                   CYL2D REGION  7

CAPACITOR      VOLUME  PROPCODE    NUM CONS   1ST CON     A/L 1       2ND CON     A/L 2
    29        1.5197E-03   2          1         3C     6.3703E+02      0      0.0000E+00
    30        1.4868E-03   2          1         31     6.2312E+02      0      0.0000E+00
    31        1.4540E-03   2          1         32     6.0919E+02      0      0.0000E+00
    32        1.4211E-03   2          1         33     5.9526E+02      0      0.0000E+00
    33        1.3883E-03   2          1         34     3.8521E+02      0      0.0000E+00
    34        1.3554E-03   2          0          C     0.0000E+00      0      0.0000E+00
GRID DIMENSIONS (FEET & DEGS):
       RADIAL          CIRCUMFERENTIAL
  6 @  1.5361E-03       1 @  6.2832E+00

CUTER RADIUS =  7.182E-02, DEPTH =  2.216E+0C, SIDES =   0  0  1  0

                                   CYL2D REGION  8

CAPACITOR      VOLUME  PROPCODE    NUM CONS   1ST CON     A/L 1       2ND CON     A/L 2
    36        1.5197E-03   2          1         37     6.3703E+02      0      0.0000E+00
    37        1.4868E-03   2          1         38     6.2312E+02      0      0.0000E+00
    38        1.4540E-03   2          1         39     6.0919E+02      0      0.0000E+00
    39        1.4211E-03   2          1         4C     5.9526E+02      0      0.0000E+00
    40        1.3883E-03   2          1         41     3.8521E+02      0      0.0000E+00
    41        1.3554E-03   2          0          C     0.0000E+00      0      0.0000E+00
GRID DIMENSIONS (FEET & DEGS):
       RADIAL          CIRCUMFERENTIAL
  6 @  1.5361E-03       1 @  6.2832E+00

CUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0

                                   CYL2D REGION  9

CAPACITOR      VOLUME  PROPCODE    NUM CCNS   1ST CON     A/L 1       2ND CON     A/L 2
    43        1.5197E-03   2          1         44     6.3703E+02      0      0.0000E+00
    44        1.4868E-03   2          1         45     6.2312E+02      0      0.0000E+00
    45        1.4540E-03   2          1         46     6.0919E+02      0      0.0000E+00
    46        1.4211E-03   2          1         47     5.9526E+02      0      0.0000E+00
    47        1.3883E-03   2          1         48     3.8521E+02      0      0.0000E+00
    48        1.3554E-03   2          0          C     0.0000E+00      0      0.0000E+00
GRID DIMENSIONS (FEET & DEGS):
       RADIAL          CIRCUMFERENTIAL
  6 @  1.5361E-03       1 @  6.2832E+00

OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0

                                   CYL2D REGION 10

CAPACITOR      VCLUME  PROPCODE    NUM CONS   1ST CON     A/L 1       2ND CCN     A/L 2
```

50	1.5197E-03	2	1	51	6.3703E+02	0	0.0000E+00
51	1.4868E-03	2	1	52	6.2312E+02	0	0.0000E+00
52	1.4540E-03	2	1	53	6.0919E+02	0	0.0000E+00
53	1.4211E-03	2	1	54	5.9526E+02	0	0.0000E+00
54	1.3883E-03	2	1	55	3.8521E+02	0	0.0000E+00
55	1.3554E-03	2	0	C	0.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
6 @ 1.5361E-03 1 @ 6.2832E+00

OUTER RADIUS = 7.182E-02, DEPTH = 2.216E+C0, SIDES = 0 0 1 0

CYL2I REGION 11

CAPACITOR	VOLUME	PROPCODE	NUM CCNS	1ST CON	A/L 1	2ND CON	A/L 2
62	1.7388E-03	3	1	63	5.5409E+02	0	0.0000E+00
63	1.6957E-03	3	1	64	5.4016E+02	0	0.0000E+00
64	1.6525E-03	3	1	65	3.4849E+02	0	0.0000E+00
65	1.6094E-03	3	0	C	0.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
4 @ 1.7604E-03 1 @ 6.2832E+00

CUTER RADIUS = 7.182E-02, DEPTH = 2.216E+CC, SIDES = 0 0 1 0

CYL2I REGION 12

CAPACITOR	VCLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
67	1.7388E-03	3	1	68	5.54C9E+02	0	0.0000E+00
68	1.6957E-03	3	1	69	5.4016E+02	0	0.0000E+00
69	1.6525E-03	3	1	7C	3.4849E+02	0	0.0000E+00
70	1.6094E-03	3	0	C	0.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
4 @ 1.7604E-03 1 @ 6.2832E+00

CUTER RADIUS = 7.182E-02, DEPTH = 2.216E+C0, SIDES = 0 0 1 0

CYL2I REGION 13

CAPACITOR	VCLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
72	1.7388E-03	3	1	73	5.54C9E+02	0	0.0000E+00
73	1.6957E-03	3	1	74	5.4016E+02	0	0.0000E+00
74	1.6525E-03	3	1	75	3.4849E+02	0	0.0000E+00
75	1.6094E-03	3	0	C	0.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
4 @ 1.7604E-03 1 @ 6.2832E+00

OUTER RADIUS = 7.182E-02, DEPTH = 2.216E+00, SIDES = 0 0 1 0

CYL2I REGION 14

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
77	1.7388E-03	3	1	78	5.5409E+02	0	0.0000E+00
78	1.6957E-03	3	1	79	5.4016E+02	0	0.0000E+00
79	1.6525E-03	3	1	80	3.4849E+02	0	0.0000E+00
80	1.6094E-03	3	0	0	0.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
4 @ 1.7604E-03 1 @ 6.2832E+00

OUTER RADIUS = 7.182E-02, DEPTH = 2.216E+00, SIDES = 0 0 1 0

CYL2D REGION 15

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
82	1.7388E-03	3	1	83	5.5409E+02	0	0.0000E+00
83	1.6957E-03	3	1	84	5.4016E+02	0	0.0000E+00
84	1.6525E-03	3	1	85	3.4849E+02	0	0.0000E+00
85	1.6094E-03	3	0	0	0.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
4 @ 1.7604E-03 1 @ 6.2832E+00

OUTER RADIUS = 7.182E-02, DEPTH = 2.216E+00, SIDES = 0 0 1 0

CYL2D REGION 16

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
102	2.6813E-03	1	1	103	2.3223E+02	0	0.0000E+00
103	2.5773E-03	1	0	0	0.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
2 @ 2.7333E-03 1 @ 6.2832E+00

OUTER RADIUS = 7.182E-02, DEPTH = 2.216E+00, SIDES = 0 0 1 0

CYL2D REGION 17

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
105	2.6813E-03	1	1	106	2.3223E+02	0	0.0000E+00
106	2.5773E-03	1	0	0	0.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
2 @ 2.7333E-03 1 @ 6.2832E+00

OUTER RADIUS = 7.182E-02, DEPTH = 2.216E+00, SIDES = 0 0 1 0

CYL2D REGION 18

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
108	2.6813E-03	1	1	109	2.3223E+02	0	0.0000E+00
109	2.5773E-03	1	0	0	0.0000E+00	0	0.0000E+00

```
GRID DIMENSIONS (FEET & DEGS):
            RADIAL          CIRCUMFERENTIAL
   2 @   2.7333E-03      1 @    6.2832E+00

OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0
```

CYL2I REGION 19

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
111	2.6813E-03	1	1	112	2.3223E+02	0	0.0000E+00
112	2.5773E-03	1	0	0	0.0000E+00	0	0.0000E+00

```
GRID DIMENSIONS (FEET & DEGS):
            RADIAL          CIRCUMFERENTIAL
   2 @   2.7333E-03      1 @    6.2832E+00

OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0
```

CYL2I REGION 20

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
114	2.6813E-03	1	1	115	2.3223E+02	0	0.0000E+00
115	2.5773E-03	1	0	0	0.0000E+00	0	0.0000E+00

```
GRID DIMENSIONS (FEET & DEGS):
            RADIAL          CIRCUMFERENTIAL
   2 @   2.7333E-03      1 @    6.2832E+00

OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0
```

CYL2I REGION 21

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
122	1.5197E-03	2	1	123	6.3703E+02	0	0.0000E+00
123	1.4868E-03	2	1	124	6.2312E+02	0	0.0000E+00
124	1.4540E-03	2	1	125	6.0919E+02	0	0.0000E+00
125	1.4211E-03	2	1	126	5.9526E+02	0	0.0000E+00
126	1.3883E-03	2	1	127	3.8521E+02	0	0.0000E+00
127	1.3554E-03	2	0	0	0.0000E+00	0	0.0000E+00

```
GRID DIMENSIONS (FEET & DEGS):
            RADIAL          CIRCUMFERENTIAL
   6 @   1.5361E-03      1 @    6.2832E+00

OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0
```

CYL2I REGION 22

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
129	1.5197E-03	2	1	130	6.3703E+02	0	0.0000E+00
130	1.4868E-03	2	1	131	6.2312E+02	0	0.0000E+00
131	1.4540E-03	2	1	132	6.0919E+02	0	0.0000E+00
132	1.4211E-03	2	1	133	5.9526E+02	0	0.0000E+00
133	1.3883E-03	2	1	134	3.8521E+02	0	0.0000E+00
134	1.3554E-03	2	0	0	0.0000E+00	0	0.0000E+00

```
GRID DIMENSIONS (FEET & DEGS):
        RADIAL          CIRCUMFERENTIAL
  6 @   1.5361E-03        1 @   6.2832E+00

OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0
```

CYL2I REGION 23

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
136	1.5197E-03	2	1	137	6.3703E+02	0	0.0000E+00
137	1.4868E-03	2	1	138	6.2312E+02	0	0.0000E+00
138	1.4540E-03	2	1	139	6.0919E+02	0	0.0000E+00
139	1.4211E-03	2	1	140	5.9526E+02	0	0.0000E+00
140	1.3883E-03	2	1	141	3.8521E+02	0	0.0000E+00
141	1.3554E-03	2	0	0	0.0000E+00	0	0.0000E+00

```
GRID DIMENSIONS (FEET & DEGS):
        RADIAL          CIRCUMFERENTIAL
  6 @   1.5361E-03        1 @   6.2832E+00

OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0
```

CYL2I REGION 24

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
143	1.5197E-03	2	1	144	6.3703E+02	0	0.0000E+00
144	1.4868E-03	2	1	145	6.2312E+02	0	0.0000E+00
145	1.4540E-03	2	1	146	6.0919E+02	0	0.0000E+00
146	1.4211E-03	2	1	147	5.9526E+02	0	0.0000E+00
147	1.3883E-03	2	1	148	3.8521E+02	0	0.0000E+00
148	1.3554E-03	2	0	0	0.0000E+00	0	0.0000E+00

```
GRID DIMENSIONS (FEET & DEGS):
        RADIAL          CIRCUMFERENTIAL
  6 @   1.5361E-03        1 @   6.2832E+00

OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0
```

CYL2I REGION 25

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
150	1.5197E-03	2	1	151	6.3703E+02	0	0.0000E+00
151	1.4868E-03	2	1	152	6.2312E+02	0	0.0000E+00
152	1.4540E-03	2	1	153	6.0919E+02	0	0.0000E+00
153	1.4211E-03	2	1	154	5.9526E+02	0	0.0000E+00
154	1.3883E-03	2	1	155	3.8521E+02	0	0.0000E+00
155	1.3554E-03	2	0	0	0.0000E+00	0	0.0000E+00

```
GRID DIMENSIONS (FEET & DEGS):
        RADIAL          CIRCUMFERENTIAL
  6 @   1.5361E-03        1 @   6.2832E+00

OUTER RADIUS =  7.182E-02, DEPTH =  2.216E+00, SIDES =   0  0  1  0
```

CYL2I REGION 26

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
162	1.7388E-03	3	1	163	5.5409E+02	0	0.0000E+00
163	1.6957E-03	3	1	164	5.4016E+02	0	0.0000E+00
164	1.6525E-03	3	1	165	3.4849E+02	0	0.0000E+00
165	1.6094E-03	3	0	C	0.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
4 @ 1.7604E-03 1 @ 6.2832E+00

OUTER RADIUS = 7.182E-02, DEPTH = 2.216E+00, SIDES = 0 0 1 0

CYL2I REGION 27

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
167	1.7388E-03	3	1	168	5.5409E+02	0	0.0000E+00
168	1.6957E-03	3	1	169	5.4016E+02	0	0.0000E+00
169	1.6525E-03	3	1	170	3.4849E+02	0	0.0000E+00
170	1.6094E-03	3	0	0	0.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
4 @ 1.7604E-03 1 @ 6.2832E+00

OUTER RADIUS = 7.182E-02, DEPTH = 2.216E+00, SIDES = 0 0 1 0

CYL2I REGION 28

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
172	1.7388E-03	3	1	173	5.5409E+02	0	0.0000E+00
173	1.6957E-03	3	1	174	5.4016E+02	0	0.0000E+00
174	1.6525E-03	3	1	175	3.4849E+02	0	0.0000E+00
175	1.6094E-03	3	0	C	C.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
4 @ 1.7604E-03 1 @ 6.2832E+00

OUTER RADIUS = 7.182E-02, DEPTH = 2.216E+00, SIDES = 0 0 1 0

CYL2I REGION 29

CAPACITOR	VOLUME	PROPCODE	NUM CONS	1ST CON	A/L 1	2ND CON	A/L 2
177	1.7388E-03	3	1	178	5.5409E+02	0	0.0000E+00
178	1.6957E-03	3	1	179	5.4016E+02	0	0.0000E+00
179	1.6525E-03	3	1	180	3.4849E+02	0	0.0000E+00
180	1.6094E-03	3	0	C	0.0000E+00	0	0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
RADIAL CIRCUMFERENTIAL
4 @ 1.7604E-03 1 @ 6.2832E+00

OUTER RADIUS = 7.182E-02, DEPTH = 2.216E+00, SIDES = 0 0 1 0

CYL2I REGION 30

```
CAPACITOR     VOLUME  PROPCODE   NUM CONS  1ST CON      A/L 1       2ND CON      A/L 2
   182     1.7388E-03    3          1       183     5.5409E+02        0     0.0000E+00
   183     1.6957E-03    3          1       184     5.4016E+02        0     0.0000E+00
   184     1.6525E-03    3          1       185     3.4849E+02        0     0.0000E+00
   185     1.6094E-03    3          0         0     0.0000E+00        0     0.0000E+00

GRID DIMENSIONS (FEET & DEGS):
          RADIAL         CIRCUMFERENTIAL
  4 @   1.7604E-03      1 @    6.2832E+00

OUTER RADIUS =   7.182E-02, DEPTH =   2.216E+00, SIDES =    0  0  1  0


                          THE DATA FOR SUBROUTINE READCP:
                  GEOMETRY DEFINITIONS FOR SURFACE NODES
 NODE      VOLUME       MATR'L       CONS         FIRST         A/L
   1     0.000E+00        1            1            2     7.430E+02 0.000E+00 0.000E+00
   4     0.000E+00        1            1            5     7.430E+02 0.000E+00 0.000E+00
   7     0.000E+00        1            1            8     7.430E+02 0.000E+00 0.000E+00
  10     0.000E+00        1            1           11     7.430E+02 0.000E+00 0.000E+00
  13     0.000E+00        1            1           14     7.430E+02 0.000E+00 0.000E+00
  21     0.000E+00        2            1           22     1.294E+03 0.000E+00 0.000E+00
  28     0.000E+00        2            1           29     1.294E+03 0.000E+00 0.000E+00
  35     0.000E+00        2            1           36     1.294E+03 0.000E+00 0.000E+00
  42     0.000E+00        2            1           43     1.294E+03 0.000E+00 0.000E+00
  49     0.000E+00        2            1           50     1.294E+03 0.000E+00 0.000E+00
  61     0.000E+00        3            1           62     1.136E+03 0.000E+00 0.000E+00
  66     0.000E+00        3            1           67     1.136E+03 0.000E+00 0.000E+00
  71     0.000E+00        3            1           72     1.136E+03 0.000E+00 0.000E+00
  76     0.000E+00        3            1           77     1.136E+03 0.000E+00 0.000E+00
  81     0.000E+00        3            1           82     1.136E+03 0.000E+00 0.000E+00
 101     0.000E+00        1            1          102     7.430E+02 0.000E+00 0.000E+00
 104     0.000E+00        1            1          105     7.430E+02 0.000E+00 0.000E+00
 107     0.000E+00        1            1          108     7.430E+02 0.000E+00 0.000E+00
 110     0.000E+00        1            1          111     7.430E+02 0.000E+00 0.000E+00
 113     0.000E+00        1            1          114     7.430E+02 0.000E+00 0.000E+00
 121     0.000E+00        2            1          122     1.294E+03 0.000E+00 0.000E+00
 128     0.000E+00        2            1          129     1.294E+03 0.000E+00 0.000E+00
 135     0.000E+00        2            1          136     1.294E+03 0.000E+00 0.000E+00
 142     0.000E+00        2            1          143     1.294E+03 0.000E+00 0.000E+00
 149     0.000E+00        2            1          150     1.294E+03 0.000E+00 0.000E+00
 161     0.000E+00        3            1          162     1.136E+03 0.000E+00 0.000E+00
 166     0.000E+00        3            1          167     1.136E+03 0.000E+00 0.000E+00
 171     0.000E+00        3            1          172     1.136E+03 0.000E+00 0.000E+00
 176     0.000E+00        3            1          177     1.136E+03 0.000E+00 0.000E+00
 181     0.000E+00        3            1          182     1.136E+03 0.000E+00 0.000E+00
THE ENTHALPY VALUES IN THE AIR PROPERTY TABLES ARE REFERENCED TO    530.00 DEGREES RANKINE.

   THE CONVERSION FACTORS USED ARE: PRESSURE --  2.1154E+03; TEMPERATURE --  1.0000E+00; ENTHALPY --  1.0000E+00


                           THE DATA FOR SUBROUTINE READAL:
     THE 1962 STANDARD DAY:  TEMP (R), ALTITUDE(FEET), PRESSURE & SONIC VEL.
 ALTITUDE         TEMP.          PRESSURE      SONIC VELOCITY    TSPACE
 0.000000E+00   5.187000E+02   2.115360E+03   1.116400E+03   0.000000E+00
 5.000000E+03   5.007998E+02   1.760146E+03   1.097100E+03   0.000000E+00
 1.000000E+04   4.830000E+02   1.455008E+03   1.077400E+03   0.000000E+00
 1.500000E+04   4.652000E+02   1.194311E+03   1.057400E+03   0.000000E+00
 2.000000E+04   4.473999E+02   9.728750E+02   1.036900E+03   0.000000E+00
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2.500000E+04	4.295999E+02	7.860251E+02	1.016100E+03	0.000000E+00
3.000000E+04	4.117998E+02	6.294041E+02	9.947998E+02	0.000000E+00
3.500000E+04	3.940999E+02	4.591401E+02	9.731399E+02	0.000000E+00
3.620000E+04	3.899700E+02	4.714077E+02	9.680798E+02	0.000000E+00
4.000000E+04	3.899700E+02	3.929702E+02	9.680798E+02	0.000000E+00
4.500000E+04	3.899700E+02	3.093289E+02	9.680798E+02	0.000000E+00
5.000000E+04	3.899700E+02	2.435202E+02	9.680798E+02	0.000000E+00
5.500000E+04	3.899700E+02	1.917235E+02	9.680798E+02	0.000000E+00
6.000000E+04	3.899700E+02	1.509647E+02	9.680798E+02	0.000000E+00
6.500000E+04	3.899700E+02	1.188874E+02	9.680798E+02	0.000000E+00
6.800000E+04	3.911499E+02	1.030328E+02	9.695498E+02	0.000000E+00
7.000000E+04	3.922000E+02	9.368929E+01	9.708999E+02	0.000000E+00
7.500000E+04	3.948999E+02	7.396143E+01	9.742000E+02	0.000000E+00
8.000000E+04	3.977000E+02	5.848969E+01	9.775999E+02	0.000000E+00
9.000000E+04	4.030999E+02	3.676494E+01	9.842000E+02	0.000000E+00
9.500000E+04	4.057998E+02	2.921945E+01	9.875999E+02	0.000000E+00
1.000000E+05	4.085000E+02	2.326260E+01	9.908999E+02	0.000000E+00
1.100000E+05	4.183838E+02	1.483127E+01	1.002720E+03	0.000000E+00
1.400000E+05	4.638999E+02	4.204489E+00	1.055880E+03	0.000000E+00
1.555000E+05	4.871699E+02	2.302062E+00	1.082020E+03	0.000000E+00
1.720000E+05	4.871699E+02	1.232260E+00	1.082020E+03	0.000000E+00
1.800000E+05	4.785498E+02	9.079967E-01	1.072400E+03	0.000000E+00
2.000000E+05	4.569900E+02	4.132778E-01	1.047980E+03	0.000000E+00
2.625000E+05	3.251699E+02	2.160205E-02	8.840000E+02	0.000000E+00
2.950000E+05	3.251699E+02	3.465054E-03	8.840000E+02	0.000000E+00

THE CONVERSION FACTORS USED ARE: PRESSURE -- 2.1154E+03; TEMPERATURE -- 1.0000E+00

AERODYNAMIC HEATING DATA

CASE	FLOW FIELD	TRAJ TABLE	FLOW TABLE	TRANS RE NO.	SURFACE NODE	INDEPTH NODE	SURFACE AREA	REFERENCE LENGTH	ENTRANCE RATIO
1	PLATE	1	1	1.000E+06	1	2	1.000E+00	1.333E-01	1.000E+00
2	PLATE	2	1	1.000E+06	4	5	1.000E+00	1.333E-01	1.000E+00
3	PLATE	3	1	1.000E+06	7	8	1.000E+00	1.333E-01	1.000E+00
4	PLATE	4	1	1.000E+06	10	11	1.000E+00	1.333E-01	1.000E+00
5	PLATE	5	1	1.000E+06	13	14	1.000E+00	1.333E-01	1.000E+00
6	PLATE	1	1	1.000E+06	21	22	1.000E+00	1.333E-01	1.000E+00
7	PLATE	2	1	1.000E+06	28	29	1.000E+00	1.333E-01	1.000E+00
8	PLATE	3	1	1.000E+06	35	36	1.000E+00	1.333E-01	1.000E+00
9	PLATE	4	1	1.000E+06	42	43	1.000E+00	1.333E-01	1.000E+00
10	PLATE	5	1	1.000E+06	49	50	1.000E+00	1.333E-01	1.000E+00
11	PLATE	1	1	1.000E+06	61	62	1.000E+00	1.333E-01	1.000E+00
12	PLATE	2	1	1.000E+06	66	67	1.000E+00	1.333E-01	1.000E+00
13	PLATE	3	1	1.000E+06	71	72	1.000E+00	1.333E-01	1.000E+00
14	PLATE	4	1	1.000E+06	76	77	1.000E+00	1.333E-01	1.000E+00
15	PLATE	5	1	1.000E+06	81	82	1.000E+00	1.333E-01	1.000E+00
16	PLATE	6	1	1.000E+06	101	102	1.000E+00	1.333E-01	1.000E+00
17	PLATE	7	1	1.000E+06	104	105	1.000E+00	1.333E-01	1.000E+00
18	PLATE	8	1	1.000E+06	107	108	1.000E+00	1.333E-01	1.000E+00
19	PLATE	9	1	1.000E+06	110	111	1.000E+00	1.333E-01	1.000E+00
20	PLATE	10	1	1.000E+06	113	114	1.000E+00	1.333E-01	1.000E+00
21	PLATE	6	1	1.000E+06	121	122	1.000E+00	1.333E-01	1.000E+00
22	PLATE	7	1	1.000E+06	128	129	1.000E+00	1.333E-01	1.000E+00
23	PLATE	8	1	1.000E+06	135	136	1.000E+00	1.333E-01	1.000E+00
24	PLATE	9	1	1.000E+06	142	143	1.000E+00	1.333E-01	1.000E+00
25	PLATE	10	1	1.000E+06	149	150	1.000E+00	1.333E-01	1.000E+00
26	PLATE	6	1	1.000E+06	161	162	1.000E+00	1.333E-01	1.000E+00
27	PLATE	7	1	1.000E+06	166	167	1.000E+00	1.333E-01	1.000E+00
28	PLATE	8	1	1.000E+06	171	172	1.000E+00	1.333E-01	1.000E+00

29	PLATE	9	1	1.000E+06	176	177	1.000E+00	1.333E-01	1.000E+00
30	PLATE	10	1	1.000E+06	181	182	1.000E+00	1.333E-01	1.000E+00

THE DATA FOR READFL STATEMENT # 1:
LOCAL FLOW CONDITIONS VON-KARMON 2.1 F.RATIO, X/I = .0389 (BBA-AS-05-65)

MACH #	MACH RATIO	PRESSURE RATIO	VEL. GRADIENT FACTOR
0.000	1.000	1.000	1.000
0.900	1.000	1.000	1.000
1.000	1.000	1.000	1.000
1.050	0.870	1.100	1.000
1.100	0.750	1.200	1.000
1.200	0.700	1.300	1.000
1.400	0.670	1.600	1.000
2.000	0.670	2.450	1.000
3.000	0.670	4.300	1.000
4.000	0.660	6.500	1.000
5.000	0.632	9.600	1.000
6.000	0.600	13.200	1.000
8.000	0.540	22.500	1.000
10.000	0.485	34.300	1.000
12.000	0.430	47.600	1.000
14.000	0.385	68.400	1.000
16.000	0.340	89.000	1.000

THE DATA FOR SUBROUTINE READAPC:

AERODYNAMIC DATA FOR RT MISS & VKRMN RADOME

ALPHA	MACH	CNM	CNB	CAB	XCP/L
0.0000	0.0000	0.0000	0.0000	0.1800	0.5000
0.0000	1.0000	0.0000	0.0000	0.1800	0.5500
0.0000	1.5000	0.0000	0.0000	0.1610	0.5430
0.0000	2.0000	0.0000	0.0000	0.1500	0.5370
0.0000	2.2500	0.0000	0.0000	0.1440	0.5300
0.0000	2.5000	0.0000	0.0000	0.1400	0.5290
0.0000	2.7500	0.0000	0.0000	0.1360	0.5280
0.0000	3.0000	0.0000	0.0000	0.1350	0.5270
0.0000	3.5000	0.0000	0.0000	0.1300	0.5260
0.0000	4.0000	0.0000	0.0000	0.1260	0.5260
0.0000	6.0000	0.0000	0.0000	0.1140	0.5200
0.0000	8.0000	0.0000	0.0000	0.1060	0.5150
0.0000	10.0000	0.0000	0.0000	0.1010	0.5100
0.0000	12.0000	0.0000	0.0000	0.0970	0.5050

AERODYNAMIC DATA FOR BT MISS & VKRMN RADOME

ALPHA	MACH	CNM	CNR	CAR	XCP/L	
4.0000	0.0000	1.3000	0.0000	0.1640	0.5540	
4.0000	1.0000	0.8000	0.1600	0.1640	0.5540	
4.0000	1.5000	0.7000	0.1500	0.1540	0.5460	
4.0000	2.0000	0.6000	0.1500	0.1500	0.5400	
4.0000	2.2500	0.5500	0.1460	0.1440	0.5380	
4.0000	2.5000	0.5100	0.1430	0.1420	0.5360	
4.0000	2.7500	0.5000	0.1400	0.1400	0.5340	
4.0000	3.0000	0.4800	0.1390	0.1380	0.5330	
4.0000	3.5000	0.4500	0.1380	0.1360	0.5310	
4.0000	4.0000	0.4000	0.1370	0.1340	0.5300	
4.0000	6.0000	0.3500	0.1300	0.1260	0.5300	
4.0000	8.0000	0.3000	0.1200	0.1210	0.5300	
4.0000	10.0000	0.3000	0.1050	0.1180	0.5300	
4.0000	12.0000	0.3000	0.0950	0.1170	0.5300	

AERODYNAMIC DATA FOR BT MISS & VKRMN RADOME

ALPHA	MACH	CNM	CNB	CAB	XCP/I
8.0000	0.0000	2.4000	0.0000	0.1490	0.5590
8.0000	1.0000	1.7000	0.3500	0.1490	0.5590
8.0000	1.5000	1.5000	0.3120	0.1480	0.5510
8.0000	2.0000	1.3200	0.3050	0.1470	0.5450
8.0000	2.2500	1.3000	0.3030	0.1470	0.5430
8.0000	2.5000	1.2800	0.3010	0.1470	0.5410
8.0000	2.7500	1.2400	0.3000	0.1470	0.5400
8.0000	3.0000	1.2000	0.2900	0.1460	0.5390
8.0000	3.5000	1.2000	0.2800	0.1460	0.5370
8.0000	4.0000	1.1800	0.2770	0.1450	0.5350
8.0000	6.0000	1.0500	0.2500	0.1430	0.5350
8.0000	8.0000	0.9500	0.2400	0.1410	0.5350
8.0000	10.0000	0.9000	0.2400	0.1400	0.5350
8.0000	12.0000	0.8900	0.2400	0.1400	0.5350

AERODYNAMIC DATA FOR BT MISS & VKRMN RADOME

ALPHA	MACH	CNM	CNR	CAR	XCP/L
12.0000	0.0000	3.5000	0.0000	0.1280	0.5640
12.000C	1.0000	2.7000	0.5000	0.1280	0.5640
12.0000	1.5000	2.4000	C.4850	0.1400	0.5560
12.0000	2.0000	2.2700	0.4750	0.1480	0.5500
12.0000	2.2500	2.2100	C.4700	0.1500	0.5460
12.0000	2.5000	2.2000	0.4650	0.1540	0.5470
12.0000	2.7500	2.1500	0.4600	0.1550	0.5460
12.0000	3.0000	2.1000	0.4500	0.1560	0.5450
12.0000	3.5000	2.C800	C.4300	0.1580	0.5430
12.000C	4.0000	2.C000	0.4250	0.1590	0.5400
12.0000	6.0000	1.8600	C.3800	0.1590	0.5400
12.0000	8.0000	1.7600	0.3600	0.1600	0.5400
12.0000	10.0000	1.7000	0.3500	0.1600	0.5400
12.0000	12.0000	1.6300	0.3400	0.1600	0.5400

AERODYNAMIC DATA FOR BT MISS & VKRMN RADOME

ALPHA	MACH	CNM	CNR	CAR	XCP/L
16.0000	0.0000	4.8000	0.0000	0.1120	0.5680
16.0000	1.0000	3.9500	0.6900	0.1120	0.5680
16.0000	1.5000	3.6000	0.6750	0.1320	0.5610
16.0000	2.0000	3.5000	0.6600	0.1480	0.5550
16.0000	2.2500	3.4300	0.6500	0.1560	0.5540
16.0000	2.5000	3.4000	0.6300	0.1620	0.5530
16.0000	2.7500	3.3500	0.6250	0.1660	0.5520
16.0000	3.0000	3.3000	0.6200	0.1690	0.5500
16.0000	3.5000	3.2200	0.6000	0.1720	0.5480
16.0000	4.0000	3.2000	0.5750	0.1740	0.5460
16.0000	6.0000	3.1000	0.5200	0.1760	0.5460
16.0000	8.0000	2.9000	0.4900	0.1780	0.5460
16.0000	10.0000	2.8000	0.4700	0.1780	0.5460
16.0000	12.0000	2.7200	0.4600	0.1790	0.5460

AERODYNAMIC DATA FOR BT MISS & VKRMN RADOME

ALPHA	MACH	CMM	CNR	CAR	XCP/L
20.0000	0.0000	6.0000	0.0000	0.0650	0.5750
20.0000	1.0000	5.3500	0.9100	0.0650	0.5750
20.0000	1.5000	5.1000	0.8850	0.1190	0.5660
20.0000	2.0000	4.9000	0.8650	0.1500	0.5600
20.0000	2.2500	4.8000	0.8500	0.1620	0.5590
20.0000	2.5000	4.7000	0.8250	0.1720	0.5580
20.0000	2.7500	4.6000	0.8150	0.1800	0.5580
20.0000	3.0000	4.5000	0.8000	0.1860	0.5560
20.0000	3.5000	4.3500	0.7700	0.1940	0.5530
20.0000	4.0000	4.2000	0.7400	0.1980	0.5510
20.0000	6.0000	3.8000	0.6500	0.2020	0.5510
20.0000	8.0000	3.6000	0.6000	0.2040	0.5510
20.0000	10.0000	3.5000	0.5700	0.2040	0.5510
20.0000	12.0000	3.4000	0.5500	0.2040	0.5510

AERODYNAMIC LOAD DATA

CASE	RADOME LENGTH	R BASE	THICKNESS	CM STATION	WEIGHT	MANEUVER G'S	ALPHA DOT	ALPHA DOT2	TRAJID
1	2.8300E+01	6.7500E+00	6.5600E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	1
2	2.8300E+01	6.7500E+00	6.5600E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	2
3	2.8300E+01	6.7500E+00	6.5600E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	3
4	2.8300E+01	6.7500E+00	6.5600E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	4
5	2.8300E+01	6.7500E+00	6.5600E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	5
6	2.8300E+01	6.7500E+00	1.1060E-01	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	1
7	2.8300E+01	6.7500E+00	1.1060E-01	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	2
8	2.8300E+01	6.7500E+00	1.1060E-01	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	3
9	2.8300E+01	6.7500E+00	1.1060E-01	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	4
10	2.8300E+01	6.7500E+00	1.1060E-01	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	5
11	2.8300E+01	6.7500E+00	8.4500E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	1
12	2.8300E+01	6.7500E+00	8.4500E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	2
13	2.8300E+01	6.7500E+00	8.4500E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	3
14	2.8300E+01	6.7500E+00	8.4500E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	4
15	2.8300E+01	6.7500E+00	8.4500E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	5
16	2.8300E+01	6.7500E+00	6.5600E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	6
17	2.8300E+01	6.7500E+00	6.5600E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	7
18	2.8300E+01	6.7500E+00	6.5600E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	8
19	2.8300E+01	6.7500E+00	6.5600E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	9
20	2.8300E+01	6.7500E+00	6.5600E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	10
21	2.8300E+01	6.7500E+00	1.1060E-01	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	6
22	2.8300E+01	6.7500E+00	1.1060E-01	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	7
23	2.8300E+01	6.7500E+00	1.1060E-01	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	8
24	2.8300E+01	6.7500E+00	1.1060E-01	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	9
25	2.8300E+01	6.7500E+00	1.1060E-01	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	10
26	2.8300E+01	6.7500E+00	8.4500E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	6
27	2.8300E+01	6.7500E+00	8.4500E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	7
28	2.8300E+01	6.7500E+00	8.4500E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	8
29	2.8300E+01	6.7500E+00	8.4500E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	9
30	2.8300E+01	6.7500E+00	8.4500E-02	1.1000E+02	1.5000E+03	9.6600E+02	0.0000E+00	6.5000E+02	10

THE DATA FOR READTM STATEMENT # 1

TIME TABLE FOR V1 TRAJ @ QE = 20

TIME	ALT	VELOCITY	QFAD IN	MAX ALPHA	
0.000	0.000	1.000	0.000	20.000	0.000
45.000	92345.438	12000.000	0.000	20.000	0.000

THE DATA FOR READTM STATEMENT # 2

TIME TABLE FOR V2 TRAJ @ QE = 20

TIME	ALT	VELOCITY	QFAD IN	MAX ALPHA	
0.000	0.000	1.000	0.000	20.000	0.000
30.000	61563.598	12000.000	0.000	20.000	0.000

THE DATA FOR READTM STATEMENT # 3

TIME TABLE FOR V3 TRAJ @ QE = 20

TIME	ALT	VELOCITY	QFAD IN	MAX ALPHA	
0.000	0.000	1.000	0.000	20.000	0.000
20.000	41042.398	12000.000	0.000	20.000	0.000

THE DATA FOR READTM STATEMENT # 4

TIME TABLE FOR V4 TRAJ @ QE = 20

TIME	ALT	VELOCITY	QFAD IN	MAX ALPHA

```
 0.000     0.000     1.000      0.000    20.000     0.000
10.000 20521.199 12000.000      0.000    20.000     0.000

                   THE DATA FOR READTH STATEMENT #  5
          TIME TABLE FOR V5 TRAJ @ QE = 20
TIME       ALT       VELOCITY  QRAD IN    MAX ALPHA
 0.000     0.000     1.000      0.000    20.000     0.000
 5.000 10260.000 12000.000      0.000    20.000     0.000

                   THE DATA FOR READTH STATEMENT #  6
          TIME TABLE FOR V1 TRAJ @ QE = 80
TIME       ALT       VELOCITY  QRAD IN    MAX ALPHA
 0.000     0.000     1.000      0.000    20.000     0.000
27.590100000.000  7358.500      0.000    20.000     0.000
45.000100000.000 12000.000      0.000    20.000     0.000

                   THE DATA FOR READTH STATEMENT #  7
          TIME TABLE FOR V2 TRAJ @ QE = 80
TIME       ALT       VELOCITY  QRAD IN    MAX ALPHA
 0.000     0.000     1.000      0.000    20.000     0.000
22.530100000.000  9012.000      0.000    20.000     0.000
30.000100000.000 12000.000      0.000    20.000     0.000

                   THE DATA FOR READTH STATEMENT #  8
          TIME TABLE FOR V3 TRAJ @ QE = 80
TIME       ALT       VELOCITY  QRAD IN    MAX ALPHA
 0.000     0.000     1.000      0.000    20.000     0.000
18.397100000.000 11028.500      0.000    20.000     0.000
20.000100000.000 12000.000      0.000    20.000     0.000

                   THE DATA FOR READTH STATEMENT #  9
          TIME TABLE FOR V4 TRAJ @ QE = 80
TIME       ALT       VELOCITY  QRAD IN    MAX ALPHA
 0.000     0.000     1.000      0.000    20.000     0.000
10.000 55088.000 12000.000      0.000    20.000     0.000

                   THE DATA FOR READTH STATEMENT # 10
          TIME TABLE FOR V5 TRAJ @ QE = 80
TIME       ALT       VELOCITY  QRAD IN    MAX ALPHA
 0.000     0.000     1.000      0.000    20.000     0.000
 5.000 29544.000 12000.000      0.000    20.000     0.000

                   THE DATA FOR READSG STATEMENT #   1:
    THERMAL STRESS GEOMETRY DATA FOR   LIMIT  STUDY
  RADIUS      NODE   MAT CODE         INTERFACE RADIUS
                                          0.796
     0.796      3         1
                                          0.829
     0.845      2         1
     0.862      1         1
                                          0.862
EXT PRESS =  0.000E+00; INT PRESS =  0.000E+00; NO-STRESS TEMP =  5.930E+01; RADAR ANGLE =  6.500E+01; UNCONSTRAINED ENDS.
```

```
                    THE DATA FCR READSG STATEMENT #   2:

                                                  0.796
          0.796         6          1
                                                  0.829
          0.845         5          1
          0.862         4          1
                                                  0.862
EXT PRESS =  0.000E+00; INT PRESS =  0.000E+C0; NO-STRESS TEMP =  5.930E+01; RADAR ANGLE =  6.500E+01; UNCCNSTRAINED ENDS.

                    THE DATA FCR READSG STATEMENT #   3:

                                                  0.796
          0.796         9          1
                                                  0.829
          0.845         8          1
          0.862         7          1
                                                  0.862
EXT PRESS =  0.000E+00; INT PRESS =  0.000E+C0; NO-STRESS TEMP =  5.930E+01; RADAR ANGLE =  6.500E+01; UNCCNSTRAINED ENDS.

                    THE DATA FCR READSG STATEMENT #   4:

                                                  0.796
          0.796        12          1
                                                  0.829
          0.845        11          1
          0.862        10          1
                                                  0.862
EXT PRESS =  0.000E+00; INT PRESS =  0.000E+00; NO-STRESS TEMP =  5.930E+01; RADAR ANGLE =  6.500E+01; UNCCNSTRAINED ENDS.

                    THE DATA FCR READSG STATEMENT #   5:

                                                  0.796
          0.796        15          1
                                                  0.829
          0.845        14          1
          0.862        13          1
                                                  0.862
EXT PRESS =  0.000E+00; INT PRESS =  0.000E+00; NO-STRESS TEMP =  5.930E+01; RADAR ANGLE =  6.500E+01; UNCCNSTRAINED ENDS.

                    THE DATA FCR READSG STATEMENT #   6:

                                                  0.751
          0.751        27          2
          0.779        26          2
                                                  0.788
          0.797        25          2
          0.816        24          2
                                                  0.825
          0.834        23          2
                                                  0.843
```

(NOTE: Thermal stress tables for cases 7 through 29 have been omitted from this sample.)

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         0.809       179         3
                                               0.820
         0.830       178         3
                                               0.841
         0.851       177         3
         0.862       176         3
                                               0.862
EXT PRESS =  0.000E+00; INT PRESS =  0.000E+00; NO-STRESS TEMP =  5.930E+01; RADAR ANGLE =  6.500E+01; UNCCNSTRAINED ENDS.

                  THE DATA FCR READSG STATEMENT #  30:

                                               0.778
         0.778       185         3
                                               0.799
         0.809       184         3
                                               0.820
         0.830       183         3
                                               0.841
         0.851       182         3
         0.862       181         3
                                               0.862
EXT PRESS =  0.000E+00; INT PRESS =  0.000E+C0; NO-STRESS TEMP =  5.930E+01; RADAR ANGLE =  6.500E+01; UNCCNSTRAINED ENDS.
```

BORESIGHT ERRCR SLOPE DATA

CASE	FREQUENCY	APERTURE SIZE
1	3.000E+10	3.890E+00
2	3.000E+10	3.890E+00
3	3.CC0E+10	3.890E+00
4	3.000E+10	3.890E+00
5	3.000E+10	3.890E+00
6	3.000E+10	3.890E+00
7	3.000E+10	3.890E+00
8	3.000E+10	3.890E+00
9	3.0C0E+10	3.890E+00
10	3.000E+10	3.890E+00
11	3.000E+10	3.890E+00
12	3.000E+10	3.890E+00
13	3.0C0E+10	3.890E+00
14	3.000E+10	3.890E+00
15	3.000E+1C	3.890E+00
16	3.000E+10	3.890E+00
17	3.000E+10	3.890E+00
18	3.000E+10	3.890E+00
19	3.000E+1C	3.890E+00
20	3.000E+10	3.890E+00
21	3.000E+10	3.890E+00
22	3.000E+10	3.890E+00
23	3.0C0E+10	3.890E+00
24	3.000E+10	3.890E+00
25	3.000E+10	3.890E+00
26	3.000E+10	3.890E+00
27	3.000E+10	3.890E+00
28	3.000E+10	3.890E+00
29	3.000E+10	3.890E+00
30	3.000E+10	3.890E+00

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                         DIRECTORY INFORMATION FOR
                              LIMIT CASE  1

          ALUMINA AT 20 DEGREE LAUNCH ANGLE

MAXIMUM ALLOWABLE THERMAL PROPERTIES FROM MATERIAL   1 :      BORESIGHT LIMIT =   1.000E-02 DEG/DEG
                                                             MELT TEMPERATURE =   4.061E+03 DEG RANKINE
MAXIMUM ALLOWABLE MECHANICAL PROPERTIES FROM MATERIAL 1 :    MOR =   1.870E+04 PSI.

         ON TRAJECTORY #   1:
                  THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE   1
                  THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE   1
                  THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE   1
                  THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE    1
                  THE NODES SUBJECT TO MELTING ARE:     1      2      3

         ON TRAJECTORY #   2:
                  THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE   2
                  THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE   2
                  THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE   2
                  THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE    2
                  THE NODES SUBJECT TO MELTING ARE:     4      5      6

         ON TRAJECTORY #   3:
                  THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE   3
                  THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE   3
                  THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE   3
                  THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE    3
                  THE NODES SUBJECT TO MELTING ARE:     7      8      9

         ON TRAJECTORY #   4:
                  THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE   4
                  THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE   4
                  THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE   4
                  THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE    4
                  THE NODES SUBJECT TO MELTING ARE:    10     11     12

         ON TRAJECTORY #   5:
                  THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE   5
                  THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE   5
                  THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE   5
                  THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE    5
                  THE NODES SUBJECT TO MELTING ARE:    13     14     15
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                         DIRECTORY INFORMATION FOR
                              LIMIT CASE  2

            FUSED SILICA AT 20 DEGREE LAUNCH ANGLE

MAXIMUM ALLOWABLE THERMAL PROPERTIES FROM MATERIAL  2 :     BORESIGHT LIMIT =  1.000E-02 DEG/DEG
                                                            MELT TEMPERATURE =  3.600E+03 DEG RANKINE
MAXIMUM ALLOWABLE MECHANICAL PROPERTIES FROM MATERIAL 2 :   MOR =  4.000E+03 PSI.

            ON TRAJECTORY #   1:
                     THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  1
                     THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE   6
                     THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE   6
                     THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE    6
                     THE NODES SUBJECT TO MELTING ARE:      21     22     23     24
                                                            25     26     27
            ON TRAJECTORY #   2:
                     THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  2
                     THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE   7
                     THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE   7
                     THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE    7
                     THE NODES SUBJECT TO MELTING ARE:      28     29     30     31
                                                            32     33     34
            ON TRAJECTORY #   3:
                     THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  3
                     THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE   8
                     THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE   8
                     THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE    8
                     THE NODES SUBJECT TO MELTING ARE:      35     36     37     38
                                                            39     40     41
            ON TRAJECTORY #   4:
                     THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  4
                     THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE   9
                     THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE   9
                     THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE    9
                     THE NODES SUBJECT TO MELTING ARE:      42     43     44     45
                                                            46     47     48
            ON TRAJECTORY #   5:
                     THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  5
                     THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  10
                     THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  10
                     THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE   10
                     THE NODES SUBJECT TO MELTING ARE:      49     50     51     52
                                                            53     54     55
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                         DIRECTORY INFORMATION FOR
                               LIMIT CASE  3

     PYROCERAM AT 20 DEGREE LAUNCH ANGLE

MAXIMUM ALLOWABLE THERMAL PROPERTIES FROM MATERIAL  3 :    BORESIGHT LIMIT =  1.000E-02 DEG/DEG
                                                           MELT TEMPERATURE =  2.930E+03 DEG RANKINE
MAXIMUM ALLOWABLE MECHANICAL PROPERTIES FROM MATERIAL 3 :  MOR =  2.250E+04 PSI.

          ON TRAJECTORY #   1:
                      THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  1
                      THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  11
                      THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  11
                      THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  11
                      THE NODES SUBJECT TO MELTING ARE:   61      62      63      64
                                                          65
          ON TRAJECTORY #   2:
                      THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  2
                      THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  12
                      THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  12
                      THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  12
                      THE NODES SUBJECT TO MELTING ARE:   66      67      68      69
                                                          70
          ON TRAJECTORY #   3:
                      THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  3
                      THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  13
                      THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  13
                      THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  13
                      THE NODES SUBJECT TO MELTING ARE:   71      72      73      74
                                                          75
          ON TRAJECTORY #   4:
                      THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  4
                      THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  14
                      THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  14
                      THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  14
                      THE NODES SUBJECT TO MELTING ARE:   76      77      78      79
                                                          80
          ON TRAJECTORY #   5:
                      THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  5
                      THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  15
                      THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  15
                      THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  15
                      THE NODES SUBJECT TO MELTING ARE:   81      82      83      84
                                                          85
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                    DIRECTORY INFORMATION FOR
                          LIMIT CASE  4

          ALUMINA AT 80 DEGREE LAUNCH ANGLE

MAXIMUM ALLOWABLE THERMAL PROPERTIES FROM MATERIAL  1 :    BORESIGHT LIMIT =  1.000E-02 DEG/DEG
                                                          MELT TEMPERATURE =  4.061E+03 DEG RANKINE
MAXIMUM ALLOWABLE MECHANICAL PROPERTIES FROM MATERIAL 1 :  MOR =  1.870E+04 PSI.

          ON TRAJECTORY #   1:
                     THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  6
                     THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  16
                     THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  16
                     THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  16
                     THE NODES SUBJECT TO MELTING ARE:    101    102    103

          ON TRAJECTORY #   2:
                     THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  7
                     THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  17
                     THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  17
                     THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  17
                     THE NODES SUBJECT TO MELTING ARE:    104    105    106

          ON TRAJECTORY #   3:
                     THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  8
                     THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  18
                     THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  18
                     THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  18
                     THE NODES SUBJECT TO MELTING ARE:    107    108    109

          ON TRAJECTORY #   4:
                     THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  9
                     THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  19
                     THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  19
                     THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  19
                     THE NODES SUBJECT TO MELTING ARE:    110    111    112

          ON TRAJECTORY #   5:
                     THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE 10
                     THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  20
                     THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  20
                     THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  20
                     THE NODES SUBJECT TO MELTING ARE:    113    114    115
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                              DIRECTORY INFORMATION FOR
                                   LIMIT CASE  5

           FUSED SILICA AT 80 DEGREE LAUNCH ANGLE

MAXIMUM ALLOWABLE THERMAL PROPERTIES FROM MATERIAL  2 :     BORESIGHT LIMIT =  1.000E-02 DEG/DEG
                                                            MELT TEMPERATURE =  3.600E+03 DEG RANKINE
MAXIMUM ALLOWABLE MECHANICAL PROPERTIES FROM MATERIAL 2 :  MOR =  4.000E+03 PSI.

           ON TRAJECTORY #   1:
                         THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  6
                         THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  21
                         THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  21
                         THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  21
                         THE NODES SUBJECT TO MELTING ARE:   121      122      123      124
                                                             125      126      127
           ON TRAJECTORY #   2:
                         THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  7
                         THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  22
                         THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  22
                         THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  22
                         THE NODES SUBJECT TO MELTING ARE:   128      129      130      131
                                                             132      133      134
           ON TRAJECTORY #   3:
                         THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  8
                         THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  23
                         THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  23
                         THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  23
                         THE NODES SUBJECT TO MELTING ARE:   135      136      137      138
                                                             139      140      141
           ON TRAJECTORY #   4:
                         THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  9
                         THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  24
                         THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  24
                         THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  24
                         THE NODES SUBJECT TO MELTING ARE:   142      143      144      145
                                                             146      147      148
           ON TRAJECTORY #   5:
                         THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE 10
                         THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  25
                         THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  25
                         THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  25
                         THE NODES SUBJECT TO MELTING ARE:   149      150      151      152
                                                             153      154      155
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                         DIRECTORY INFORMATION FOR
                               LIMIT CASE 6

       PYROCERAM AT 80 DEGREE LAUNCH ANGLE

MAXIMUM ALLOWABLE THERMAL PROPERTIES FROM MATERIAL  3 :    BORESIGHT LIMIT =  1.000E-02 DEG/DEG
                                                         MELT TEMPERATURE =  2.930E+03 DEG RANKINE
MAXIMUM ALLOWABLE MECHANICAL PROPERTIES FROM MATERIAL 3 :  MOR =  2.250E+04 PSI.

            ON TRAJECTORY #   1:
                         THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  6
                         THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  26
                         THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  26
                         THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  26
                         THE NODES SUBJECT TO MELTING ARE:   161     162     163     164
                                                             165

            ON TRAJECTORY #   2:
                         THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  7
                         THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  27
                         THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  27
                         THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  27
                         THE NODES SUBJECT TO MELTING ARE:   166     167     168     169
                                                             170

            ON TRAJECTORY #   3:
                         THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  8
                         THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  28
                         THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  28
                         THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  28
                         THE NODES SUBJECT TO MELTING ARE:   171     172     173     174
                                                             175

            ON TRAJECTORY #   4:
                         THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE  9
                         THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  29
                         THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  29
                         THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  29
                         THE NODES SUBJECT TO MELTING ARE:   176     177     178     179
                                                             180

            ON TRAJECTORY #   5:
                         THE ALTITUDE & VELOCITY HISTORIES ARE FROM TIME TABLE 10
                         THE ATTACHMENT STRESSES ARE CALCULATED IN LOAD CASE  30
                         THE THERMAL STRESSES ARE CALCULATED IN STRESS CASE  30
                         THE BORESIGHT ERRORS ARE CALCULATED IN BORESIGHT CASE  30
                         THE NODES SUBJECT TO MELTING ARE:   161     182     183     184
                                                             185
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THE BORESIGHT ERROR FOR CASE    1 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE    2 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE    3 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE    4 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE    5 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE    6 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE    7 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE    8 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE    9 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   10 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   11 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   12 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   13 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   14 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   15 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   16 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   17 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   18 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   19 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   20 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   21 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   22 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   23 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   24 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   25 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   26 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   27 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   28 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   29 IS  0.000E+00
THE BORESIGHT ERROR FOR CASE   30 IS  0.000E+00
IN LIMIT CASE  1 TRAJECTORY   1 HAS A FINAL TIME OF  4.500E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  1 TRAJECTORY   2 HAS A FINAL TIME OF  3.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  1 TRAJECTORY   3 HAS A FINAL TIME OF  2.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  1 TRAJECTORY   4 HAS A FINAL TIME OF  1.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  1 TRAJECTORY   5 HAS A FINAL TIME OF  5.000E+00 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  2 TRAJECTORY   1 HAS A FINAL TIME OF  4.500E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  2 TRAJECTORY   2 HAS A FINAL TIME OF  3.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  2 TRAJECTORY   3 HAS A FINAL TIME OF  2.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  2 TRAJECTORY   4 HAS A FINAL TIME OF  1.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  2 TRAJECTORY   5 HAS A FINAL TIME OF  5.000E+00 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  3 TRAJECTORY   1 HAS A FINAL TIME OF  4.500E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  3 TRAJECTORY   2 HAS A FINAL TIME OF  3.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  3 TRAJECTORY   3 HAS A FINAL TIME OF  2.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  3 TRAJECTORY   4 HAS A FINAL TIME OF  1.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  3 TRAJECTORY   5 HAS A FINAL TIME OF  5.000E+00 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  4 TRAJECTORY   6 HAS A FINAL TIME OF  4.500E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  4 TRAJECTORY   7 HAS A FINAL TIME OF  3.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  4 TRAJECTORY   8 HAS A FINAL TIME OF  2.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  4 TRAJECTORY   9 HAS A FINAL TIME OF  1.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  4 TRAJECTORY  10 HAS A FINAL TIME OF  5.000E+00 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  5 TRAJECTORY   6 HAS A FINAL TIME OF  4.500E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  5 TRAJECTORY   7 HAS A FINAL TIME OF  3.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  5 TRAJECTORY   8 HAS A FINAL TIME OF  2.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  5 TRAJECTORY   9 HAS A FINAL TIME OF  1.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  5 TRAJECTORY  10 HAS A FINAL TIME OF  5.000E+00 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  6 TRAJECTORY   6 HAS A FINAL TIME OF  4.500E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  6 TRAJECTORY   7 HAS A FINAL TIME OF  3.000E+01 AND A FINAL VELOCITY OF  1.200E+04
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IN LIMIT CASE  6 TRAJECTORY   8 HAS A FINAL TIME OF  2.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  6 TRAJECTORY   9 HAS A FINAL TIME OF  1.000E+01 AND A FINAL VELOCITY OF  1.200E+04
IN LIMIT CASE  6 TRAJECTORY  10 HAS A FINAL TIME OF  5.000E+00 AND A FINAL VELOCITY OF  1.200E+04

TIME (SEC):
   4.01969E+00
                                  THERMAL CAPACITOR TEMPERATURES - DEGREES FAHRENHEIT
   1 =     60.1    2 =     60.1    3 =     60.0    4 =     64.9    5 =     64.6    6 =     64.1    7 =    162.7    8 =    156.8
   9 =    144.6   10 =   1010.1   11 =    881.0   12 =    719.7   13 =   4470.3   14 =   3672.5   15 =   2366.3   21 =     65.3
  22 =     63.0   23 =     60.7   24 =     59.7   25 =     59.3   26 =     59.2   27 =     59.2   28 =     89.5   29 =     79.3
  30 =     68.5   31 =     63.4   32 =     61.0   33 =     60.0   34 =     59.5   35 =    344.1   36 =    248.4   37 =    145.8
  38 =     95.9   39 =     73.7   40 =     65.0   41 =     61.2   42 =   1421.5   43 =   1021.3   44 =    546.1   45 =    299.1
  46 =    175.4   47 =    117.5   48 =     86.2   49 =   4834.3   50 =   4138.5   51 =   2760.7   52 =   1395.6   53 =    642.7
  54 =    333.3   55 =    185.6   61 =     61.2   62 =     60.8   63 =     60.3   64 =     59.9   65 =     59.7   66 =     70.4
  67 =     68.7   68 =     66.1   69 =     64.5   70 =     63.4   71 =    233.3   72 =    202.9   73 =    158.6   74 =    132.4
  75 =    114.0   76 =   1196.9   77 =    997.9   78 =    731.2   79 =    577.6   80 =    474.0   81 =   4686.7   82 =   3840.0
  83 =   2679.0   84 =   2015.3   85 =   1577.6  101 =     59.1  102 =     59.1  103 =     59.0  104 =     62.4  105 =     62.3
 106 =     62.0  107 =    115.0  108 =    111.3  109 =    103.3  110 =    822.1  111 =    733.7  112 =    614.7  113 =   4102.6
 114 =   3374.8  115 =   2175.7  121 =     60.7  122 =     59.6  123 =     58.8  124 =     58.7  125 =     58.8  126 =     58.9
 127 =     59.0  128 =     78.8  129 =     71.7  130 =     64.6  131 =     61.3  132 =     59.9  133 =     59.4  134 =     59.2
 135 =    272.1  136 =    191.0  137 =    110.8  138 =     77.7  139 =     65.7  140 =     61.7  141 =     60.1  142 =   1297.2
 143 =    926.2  144 =    497.0  145 =    274.2  146 =    162.7  147 =    110.6  148 =     82.6  149 =   4581.6  150 =   3911.0
 151 =   2548.8  152 =   1277.0  153 =    597.6  154 =    315.8  155 =    178.7  161 =     59.4  162 =     59.2  163 =     59.0
 164 =     58.8  165 =     58.7  166 =     66.1  167 =     64.9  168 =     63.1  169 =     62.1  170 =     61.3  171 =    170.5
 172 =    148.2  173 =    115.8  174 =     96.7  175 =     83.9  176 =   1029.4  177 =    862.7  178 =    637.4  179 =    506.4
 180 =    417.8  181 =   4391.5  182 =   3600.2  183 =   2516.6  184 =   1899.7  185 =   1491.4
SAERO BLOCK  1 WITH MACH # =    0.989. ITERATIONS =   2
SAERO BLOCK  2 WITH MACH # =    0.994. ITERATIONS =   2
SAERO BLOCK  3 WITH MACH # =    1.491. ITERATIONS =   3
SAERO BLOCK  4 WITH MACH # =    2.880. ITERATIONS =   4
SAERO BLOCK  5 WITH MACH # =    4.585. ITERATIONS =   3
SAERO BLOCK  6 WITH MACH # =    0.989. ITERATIONS =   2
SAERO BLOCK  7 WITH MACH # =    0.994. ITERATIONS =   2
SAERO BLOCK  8 WITH MACH # =    1.491. ITERATIONS =   3
SAERO BLOCK  9 WITH MACH # =    2.880. ITERATIONS =   3
SAERO BLOCK 10 WITH MACH # =    4.585. ITERATIONS =   4
SAERO BLOCK 11 WITH MACH # =    0.989. ITERATIONS =   2
SAERO BLOCK 12 WITH MACH # =    0.994. ITERATIONS =   2
SAERO BLOCK 13 WITH MACH # =    1.491. ITERATIONS =   3
SAERO BLOCK 14 WITH MACH # =    2.880. ITERATIONS =   3
SAERO BLOCK 15 WITH MACH # =    4.585. ITERATIONS =   3
SAERO BLOCK 16 WITH MACH # =    0.979. ITERATIONS =   2
SAERO BLOCK 17 WITH MACH # =    1.031. ITERATIONS =   2
SAERO BLOCK 18 WITH MACH # =    1.569. ITERATIONS =   3
SAERO BLOCK 19 WITH MACH # =    3.022. ITERATIONS =   4
SAERO BLOCK 20 WITH MACH # =    4.725. ITERATIONS =   3
SAERO BLOCK 21 WITH MACH # =    0.979. ITERATIONS =   2
SAERO BLOCK 22 WITH MACH # =    1.031. ITERATIONS =   2
SAERO BLOCK 23 WITH MACH # =    1.569. ITERATIONS =   3
SAERO BLOCK 24 WITH MACH # =    3.022. ITERATIONS =   3
SAERO BLOCK 25 WITH MACH # =    4.725. ITERATIONS =   4
SAERO BLOCK 26 WITH MACH # =    0.979. ITERATIONS =   2
SAERO BLOCK 27 WITH MACH # =    1.031. ITERATIONS =   2
SAERO BLOCK 28 WITH MACH # =    1.569. ITERATIONS =   3
SAERO BLOCK 29 WITH MACH # =    3.022. ITERATIONS =   3
SAERO BLOCK 30 WITH MACH # =    4.725. ITERATIONS =   3
THE RADOME ATTACHMENT STRESS IS     1.1788E+03 FOR CASE NO.   1. ANGLE OF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     2.6260E+03 FOR CASE NO.   2. ANGLE OF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     5.6868E+03 FOR CASE NO.   3. ANGLE OF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     1.1621E+04 FOR CASE NO.   4. ANGLE OF ATTACK =  12.638.
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THE RADOME ATTACHMENT STRESS IS     1.5516E+C4 FOR CASE NO.   5. ANGLE CF ATTACK =   5.539.
THE RADOME ATTACHMENT STRESS IS     7.0155E+C2 FOR CASE NO.   6. ANGLE OF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     1.5618E+03 FOR CASE NO.   7. ANGLE CF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     3.3820E+C3 FOR CASE NO.   8. ANGLE CF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     6.9108E+C3 FOR CASE NO.   9. ANGLE OF ATTACK =  12.638.
THE RADOME ATTACHMENT STRESS IS     9.2221E+03 FOR CASE NO.  10. ANGLE OF ATTACK =   5.539.
THE RADOME ATTACHMENT STRESS IS     9.1779E+C2 FOR CASE NO.  11. ANGLE CF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     2.0434E+C3 FOR CASE NO.  12. ANGLE OF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     4.4248E+C3 FOR CASE NO.  13. ANGLE CF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     9.0419E+C3 FOR CASE NO.  14. ANGLE OF ATTACK =  12.638.
THE RADOME ATTACHMENT STRESS IS     1.2067E+C4 FOR CASE NO.  15. ANGLE CF ATTACK =   5.539.
THE RADOME ATTACHMENT STRESS IS     1.0224E+C3 FOR CASE NO.  16. ANGLE CF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     2.0095E+C3 FOR CASE NO.  17. ANGLE OF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     3.7335E+C3 FOR CASE NO.  18. ANGLE OF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     1.0371E+C4 FOR CASE NO.  19. ANGLE OF ATTACK =  17.971.
THE RADOME ATTACHMENT STRESS IS     1.4913E+04 FOR CASE NO.  20. ANGLE OF ATTACK =   7.916.
THE RADOME ATTACHMENT STRESS IS     6.0283E+C2 FOR CASE NO.  21. ANGLE OF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     1.1858E+C3 FOR CASE NO.  22. ANGLE CF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     2.2047E+C3 FOR CASE NO.  23. ANGLE CF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     6.1323E+C3 FOR CASE NO.  24. ANGLE OF ATTACK =  17.971.
THE RADOME ATTACHMENT STRESS IS     8.8072E+03 FOR CASE NO.  25. ANGLE OF ATTACK =   7.916.
THE RADOME ATTACHMENT STRESS IS     7.8972E+C2 FOR CASE NO.  26. ANGLE OF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     1.5533E+C3 FOR CASE NO.  27. ANGLE CF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     2.8875E+C3 FOR CASE NO.  28. ANGLE OF ATTACK =  20.000.*
THE RADOME ATTACHMENT STRESS IS     8.0300E+C3 FOR CASE NO.  29. ANGLE CF ATTACK =  17.971.
THE RADOME ATTACHMENT STRESS IS     1.1535E+C4 FOR CASE NO.  30. ANGLE OF ATTACK =   7.916.
MAXIMUM THERMAL TENSILE STRESS FOR CASE  1 IS    1.6810E+01 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE  2 IS    7.9189E+01 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE  3 IS    1.9127E+03 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE  4 IS    3.4626E+04 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE  5 IS    1.2936E+05 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE  6 IS    5.3418E+00 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE  7 IS    3.0613E+01 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE  8 IS    2.9310E+02 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE  9 IS    1.6147E+03 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 10 IS    2.7449E+03 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 11 IS    1.1260E+01 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 12 IS    5.2882E+01 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 13 IS    3.5893E+03 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 14 IS    1.1531E+04 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 15 IS    2.1278E+04 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 16 IS    7.6805E+00 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 17 IS    5.2846E+01 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 18 IS    1.2645E+03 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 19 IS    2.3539E+04 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 20 IS    1.6622E+05 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 21 IS    1.2987E+00 PSI.
 ***THE ABOVE GRADIENT IS NOT MONOTONIC.  IT IS POSSIBLE THAT THE INTERPOLATION FOUTINE MAY HAVE TRUNCATED A PEAK.***
MAXIMUM THERMAL TENSILE STRESS FOR CASE 22 IS    1.8502E+01 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 23 IS    1.8855E+02 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 24 IS    1.4984E+03 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 25 IS    2.7275E+03 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 26 IS    4.4599E+00 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 27 IS    3.5107E+01 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 28 IS    1.7775E+03 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 29 IS    1.0252E+04 PSI.
MAXIMUM THERMAL TENSILE STRESS FOR CASE 30 IS    2.4893E+04 PSI.
THE BORESIGHT ERROR FOR CASE   1 IS  4.406E-C7
THE BORESIGHT ERROR FOR CASE   2 IS  1.101E-C5
THE BORESIGHT ERROR FOR CASE   3 IS  2.110E-C4
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THE BORESIGHT ERROR FOR CASE   4 IS  2.746E-02
THE BORESIGHT ERROR FOR CASE   5 IS  7.704E-02
THE BORESIGHT ERROR FOR CASE   6 IS  1.078E-05
THE BORESIGHT ERROR FOR CASE   7 IS  7.737E-05
THE BORESIGHT ERROR FOR CASE   8 IS  6.753E-04
THE BORESIGHT ERROR FOR CASE   9 IS  2.452E-03
THE BORESIGHT ERROR FOR CASE  10 IS  2.293E-02
THE BORESIGHT ERROR FOR CASE  11 IS  4.199E-07
THE BORESIGHT ERROR FOR CASE  12 IS  2.351E-06
THE BORESIGHT ERROR FOR CASE  13 IS  5.119E-04
THE BORESIGHT ERROR FOR CASE  14 IS  3.186E-03
THE BORESIGHT ERROR FOR CASE  15 IS  2.076E-02
THE BORESIGHT ERROR FOR CASE  16 IS  9.638E-07
THE BORESIGHT ERROR FOR CASE  17 IS  5.728E-06
THE BORESIGHT ERROR FOR CASE  18 IS  1.115E-04
THE BORESIGHT ERROR FOR CASE  19 IS  1.544E-02
THE BORESIGHT ERROR FOR CASE  20 IS  7.034E-02
THE BORESIGHT ERROR FOR CASE  21 IS  4.462E-06
THE BORESIGHT ERROR FOR CASE  22 IS  4.408E-05
THE BORESIGHT ERROR FOR CASE  23 IS  4.465E-04
THE BORESIGHT ERROR FOR CASE  24 IS  2.288E-03
THE BORESIGHT ERROR FOR CASE  25 IS  2.010E-02
THE BORESIGHT ERROR FOR CASE  26 IS  1.071E-06
THE BORESIGHT ERROR FOR CASE  27 IS  1.008E-06
THE BORESIGHT ERROR FOR CASE  28 IS  1.753E-04
THE BORESIGHT ERROR FOR CASE  29 IS  2.678E-03
THE BORESIGHT ERROR FOR CASE  30 IS  1.923E-02

---->  *** STRESS LIMIT OCCURRED IN LIMIT CASE  1 FOR STRESS CASE  4 AT  2.171E+00 SECONDS.

---->  *** BORESIGHT ERROR LIMIT OCCURRED IN LIMIT CASE  1 FOR BSERROR CASE  4 AT  1.464E+00 SECONDS.

---->  *** STRESS LIMIT OCCURRED IN LIMIT CASE  1 FOR STRESS CASE  5 AT  5.811E-01 SECONDS.

---->  *** BORESIGHT ERROR LIMIT OCCURRED IN LIMIT CASE  1 FOR BSERROR CASE  5 AT  5.218E-01 SECONDS.

---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  1 FOR NODE 13 AT  3.196E+00 SECONDS.

---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  1 FOR NODE 14 AT  3.940E+00 SECONDS.

---->  ***   LOAD LIMIT OCCURRED IN LIMIT CASE  2 FOR LOAD CASE  9 AT  2.327E+00 SECONDS.

---->  ***   LOAD LIMIT OCCURRED IN LIMIT CASE  2 FOR LOAD CASE 10 AT  1.744E+00 SECONDS.

---->  *** BORESIGHT ERROR LIMIT OCCURRED IN LIMIT CASE  2 FOR BSERROR CASE 10 AT  1.753E+00 SECONDS.

---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  2 FOR NODE 49 AT  2.572E+00 SECONDS.

---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  2 FOR NODE 50 AT  3.036E+00 SECONDS.

---->  *** BORESIGHT ERROR LIMIT OCCURRED IN LIMIT CASE  3 FOR BSERROR CASE 15 AT  1.936E+00 SECONDS.

---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  3 FOR NODE 81 AT  2.076E+00 SECONDS.

---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  3 FOR NODE 82 AT  2.563E+00 SECONDS.

---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  3 FOR NODE 83 AT  3.699E+00 SECONDS.

---->  *** STRESS LIMIT OCCURRED IN LIMIT CASE  4 FOR STRESS CASE 19 AT  3.193E+00 SECONDS.
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---->  *** BORESIGHT ERROR LIMIT OCCURRED IN LIMIT CASE  4 FOR BSERROR CASE 19 AT  2.603E+00 SECONDS.
---->  *** STRESS LIMIT OCCURRED IN LIMIT CASE  4 FOR STRESS CASE 20 AT  4.522E-01 SECONDS.
---->  *** BORESIGHT ERROR LIMIT OCCURRED IN LIMIT CASE  4 FOR BSERROR CASE 20 AT  5.714E-01 SECONDS.
---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  4 FOR NODE113 AT  3.486E+00 SECONDS.
---->  ***   LOAD LIMIT OCCURRED IN LIMIT CASE  5 FOR LOAD CASE 24 AT  2.622E+00 SECONDS.
---->  ***   LOAD LIMIT OCCURRED IN LIMIT CASE  5 FOR LOAD CASE 25 AT  1.826E+00 SECONDS.
---->  *** BORESIGHT ERROR LIMIT OCCURRED IN LIMIT CASE  5 FOR BSERROR CASE 25 AT  2.000E+00 SECONDS.
---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  5 FOR NODE149 AT  2.716E+00 SECONDS.
---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  5 FOR NODE150 AT  3.215E+00 SECONDS.
---->  *** STRESS LIMIT OCCURRED IN LIMIT CASE  6 FOR STRESS CASE 30 AT  3.633E+00 SECONDS.
---->  *** BORESIGHT ERROR LIMIT OCCURRED IN LIMIT CASE  6 FOR BSERROR CASE 30 AT  2.090E+00 SECONDS.
---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  6 FOR NODE181 AT  2.218E+00 SECONDS.
---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  6 FOR NODE182 AT  2.737E+00 SECONDS.
---->  *** MELT   LIMIT OCCURRED IN LIMIT CASE  6 FOR NODE183 AT  3.944E+00 SECONDS.
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Appendix D

MAXIMUM PRINT OUTPUT

The listing included here is a sample of the output printed on the MAXPRNT file during the sample problem execution.

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THE BORESIGHT ERROR FOR CASE    1 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE    2 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE    3 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE    4 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE    5 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE    6 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE    7 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE    8 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE    9 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   10 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   11 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   12 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   13 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   14 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   15 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   16 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   17 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   18 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   19 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   20 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   21 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   22 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   23 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   24 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   25 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   26 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   27 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   28 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   29 IS   0.000E+00
THE BORESIGHT ERROR FOR CASE   30 IS   0.000E+00

SAERO BLOCK #   1             MACH        VELOCITY      TEMPERATURE     PRESSURE       ENTHALPY       ITERATIONS
 ALTITUDE                     NUMBER        (FPS)         (DEG R)        (PSFA)        (BTU/#M)      ACC ENTH ERROR

8.24889E+03   FREE STREAM:    0.9894     1.072828E+03   4.892339E+02   1.279817E+03   1.304924E+01         0
              LOCAL FLOW :    0.9894     1.073497E+03   4.892339E+02   1.279817E+03  -9.943267E+00   0.000000E+00

    SURF NODE   HT COEFF (ENTH)   REYNOLDS #      T AD WALL      RAD FLUX IN     Q CONDUCT     T SURF CORR     TOT HEAT ERR
    TEMP DEG R    CONV FLUX       REF TEMP(T*)    H AD WALL      RAD FLUX SPACE  H WALL        ITERATIONS      COMPRESSIBILITY

         1       2.741455E-02    6.238961E+05    5.697661E+02    0.000000E+00   -3.032128E-01  -2.645808E-02    2.069518E-03
    5.198325E+02 3.308890E-01    5.222502E+02    9.522782E+00    2.729130E-02   -2.547052E+00       2            1.0000

SAERO BLOCK #   2             MACH        VELOCITY      TEMPERATURE     PRESSURE       ENTHALPY       ITERATIONS
 ALTITUDE                     NUMBER        (FPS)         (DEG R)        (PSFA)        (BTU/#M)      ACC ENTH ERROR

8.24889E+03   FREE STREAM:    1.4837     1.608742E+03   4.892339E+02   1.279817E+03   4.175775E+01         2
              LOCAL FLOW :    0.9941     1.181173E+03   5.880166E+02   2.199405E+03   1.369218E+01  -1.088386E-05

    SURF NODE   HT COEFF (ENTH)   REYNOLDS #      T AD WALL      RAD FLUX IN     Q CONDUCT     T SURF CORR     TOT HEAT ERR
    TEMP DEG R    CONV FLUX       REF TEMP(T*)    H AD WALL      RAD FLUX SPACE  H WALL        ITERATIONS      COMPRESSIBILITY

         4       3.721771E-02    8.577425E+05    6.851709E+02    0.000000E+00   -1.414774E+00  -1.232548E-01    1.903866E-03
    5.246648E+02 1.443918E+00    5.777151E+02    3.737521E+01    2.831152E-02   -1.421337E+00       2            1.0000
```

(Note: Aero blocks 3 through 26 have been omitted from this sample.)

SAERO BLOCK # 27 ALTITUDE		MACH NUMBER	VELOCITY (FPS)	TEMPERATURE (DEG R)	PRESSURE (PSFA)	ENTHALPY (BTU/#M)	ITERATIONS ACC ENTH ERROR
1.78415E+04	FREE STREAM:	1.5383	1.608698E+03	4.550840E+02	8.618264E+02	3.355292E+01	2
	LOCAL FLOW :	1.0307	1.187638E+03	5.526743E+02	1.547802E+03	5.381491E+00	-1.029283E-05

SURF NODE TEMP DEG R	HT COEFF (ENTH) CONV FLUX	REYNOLDS # REF TEMP(T*)	T AD WALL H AD WALL	RAD FLUX IN RAD FLUX SPACE	Q CONDUCT H WALL	T SURF CORR ITERATIONS	TOT HEAT ERR COMPRESSIBILITY
166	3.142843E-02	6.762606E+05	6.510063E+02	0.000000E+00	-9.190392E-01	-1.554851E-01	3.167782E-04
5.258979E+02	9.503474E-01	5.609189E+02	2.914818E+01	3.117600E-02	-1.090297E+00	2	1.0000

SAERO BLOCK # 28 ALTITUDE		MACH NUMBER	VELOCITY (FPS)	TEMPERATURE (DEG R)	PRESSURE (PSFA)	ENTHALPY (BTU/#M)	ITERATIONS ACC ENTH ERROR
2.18497E+04	FREE STREAM:	2.3421	2.410478E+03	4.408147E+02	7.239929E+02	9.452533E+01	2
	LOCAL FLOW :	1.5692	1.912789E+03	6.193044E+02	2.231956E+03	2.144937E+01	-2.109786E-05

SURF NODE TEMP DEG R	HT COEFF (ENTH) CONV FLUX	REYNOLDS # REF TEMP(T*)	T AD WALL H AD WALL	RAD FLUX IN RAD FLUX SPACE	Q CONDUCT H WALL	T SURF CORR ITERATIONS	TOT HEAT ERR COMPRESSIBILITY
171	2.714381E-01	1.286568E+06	8.878201E+02	0.000000E+00	-1.666911E+01	6.142635E-03	3.044475E-04
6.327825E+02	1.673431E+01	6.851167E+02	8.635803E+01	6.501830E-02	2.470743E+01	3	1.0000

SAERO BLOCK # 29 ALTITUDE		MACH NUMBER	VELOCITY (FPS)	TEMPERATURE (DEG R)	PRESSURE (PSFA)	ENTHALPY (BTU/#M)	ITERATIONS ACC ENTH ERROR
2.37515E+04	FREE STREAM:	4.7236	4.824227E+03	4.340442E+02	6.653135E+02	4.417607E+02	3
	LOCAL FLOW :	3.0219	4.285004E+03	8.412546E+02	5.817027E+03	7.503383E+01	-4.600013E-05

SURF NODE TEMP DEG R	HT COEFF (ENTH) CONV FLUX	REYNOLDS # REF TEMP(T*)	T AD WALL H AD WALL	RAD FLUX IN RAD FLUX SPACE	Q CONDUCT H WALL	T SURF CORR ITERATIONS	TOT HEAT ERR COMPRESSIBILITY
176	6.840457E-01	4.346993E+06	2.069743E+03	0.000000E+00	-1.036348E+02	8.959508E-02	9.324988E-04
1.501674E+03	1.053815E+02	1.448271E+03	3.996895E+02	1.745998E+00	2.456332E+02	3	1.0000

SAERO BLOCK # 30 ALTITUDE		MACH NUMBER	VELOCITY (FPS)	TEMPERATURE (DEG R)	PRESSURE (PSFA)	ENTHALPY (BTU/#M)	ITERATIONS ACC ENTH ERROR
2.37515E+04	FREE STREAM:	9.4463	9.647453E+03	4.340442E+02	6.653135E+02	1.836147E+03	3
	LOCAL FLOW :	4.7253	8.903746E+03	1.528978E+03	2.064680E+04	2.527658E+02	-6.904079E-05

SURF NODE TEMP DEG R	HT COEFF (ENTH) CONV FLUX	REYNOLDS # REF TEMP(T*)	T AD WALL H AD WALL	RAD FLUX IN RAD FLUX SPACE	Q CONDUCT H WALL	T SURF CORR ITERATIONS	TOT HEAT ERR COMPRESSIBILITY
181	1.563726E+00	1.202473E+07	5.790859E+03	0.000000E+00	-4.445164E+02	1.902616E-02	3.359526E-03
4.888680E+03	6.038625E+02	4.335514E+03	1.695194E+03	1.593452E+02	1.309025E+03	3	1.0006

|---- MANEUVER LOAD DATA FOR CASE 1 AT TIME = 4.020E+00 SECONDS. ----|

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```
QUADRANT ELEVATION =    2.000E+01

    NORMAL FORCE    MOMENT           STRESS 1       ALPHA          ALTITUDE
    AXIAL FORCE     LAT ACC, G'S     STRESS 2       ALPHA MAX      MACH #

     9.5627E+02     -1.1488E+04     -1.2681E+03     20.000         6.2489E+03
     1.2422E+02       2.793          1.1788E+03     20.000           0.989

  |---- MANEUVER LOAD DATA FOR CASE   2 AT TIME =   4.020E+00 SECONDS. ----|
QUADRANT ELEVATION =    2.000E+01

    NORMAL FORCE    MOMENT           STRESS 1       ALPHA          ALTITUDE
    AXIAL FORCE     LAT ACC, G'S     STRESS 2       ALPHA MAX      MACH #

     2.1155E+03     -2.5915E+04     -2.6938E+03     20.000         6.2489E+03
     3.7262E+02       7.133          2.6260E+03     20.000           1.484

  |---- MANEUVER LOAD DATA FOR CASE   3 AT TIME =   4.020E+00 SECONDS. ----|
QUADRANT ELEVATION =    2.000E+01

    NORMAL FORCE    MOMENT           STRESS 1       ALPHA          ALTITUDE
    AXIAL FORCE     LAT ACC, G'S     STRESS 2       ALPHA MAX      MACH #

     4.5736E+03     -5.6651E+04     -6.4222E+03     20.000         6.2489E+03
     1.0230E+03      16.224          5.6668E+03     20.000           2.225

  |---- MANEUVER LOAD DATA FOR CASE   4 AT TIME =   4.020E+00 SECONDS. ----|
QUADRANT ELEVATION =    2.000E+01

    NORMAL FORCE    MOMENT           STRESS 1       ALPHA          ALTITUDE
    AXIAL FORCE     LAT ACC, G'S     STRESS 2       ALPHA MAX      MACH #

     9.4165E+03     -1.2185E+05     -1.4331E+04     12.638         6.2489E+03
     3.7698E+03      30.000          1.1621E+04     20.000           4.449

  |---- MANEUVER LOAD DATA FOR CASE   5 AT TIME =   4.020E+00 SECONDS. ----|
QUADRANT ELEVATION =    2.000E+01

    NORMAL FORCE    MOMENT           STRESS 1       ALPHA          ALTITUDE
    AXIAL FORCE     LAT ACC, G'S     STRESS 2       ALPHA MAX      MACH #

     1.3915E+04     -1.6441E+05     -2.3764E+04      5.539         6.2484E+03
     1.1474E+04      30.000          1.5516E+04     20.000           8.897

  |---- MANEUVER LOAD DATA FOR CASE   6 AT TIME =   4.020E+00 SECONDS. ----|
QUADRANT ELEVATION =    2.000E+01

    NORMAL FORCE    MOMENT           STRESS 1       ALPHA          ALTITUDE
    AXIAL FORCE     LAT ACC, G'S     STRESS 2       ALPHA MAX      MACH #

     9.5627E+02     -1.1491E+04     -7.5009E+02     20.000         6.2489E+03
     1.1385E+02       2.793          7.0155E+02     20.000           0.989

  |---- MANEUVER LOAD DATA FOR CASE   7 AT TIME =   4.020E+00 SECONDS. ----|
```

(Note: Aerodynamic load data for cases 7 through 25 have been omitted from this sample.)

```
QUADRANT ELEVATION =    7.997E+01
    NORMAL FORCE   MOMENT          STRESS 1       ALPHA          ALTITUDE
    AXIAL FORCE    LAT ACC, G'S    STRESS 2       ALPHA MAX      MACH #

     1.2245E+04    -1.6436E+05     -1.1957E+04      7.916        2.3752E+04
     7.3887E+03     30.000          6.8072E+03     20.000           9.446

  |---- MANEUVER LOAD DATA FOR CASE  26 AT TIME =    4.020E+00 SECONDS. ----|
QUADRANT ELEVATION =    8.006E+01
    NORMAL FORCE   MOMENT          STRESS 1       ALPHA          ALTITUDE
    AXIAL FORCE    LAT ACC, G'S    STRESS 2       ALPHA MAX      MACH #

     7.8884E+02    -9.7747E+03     -8.2657E+02     20.000        1.4569E+04
     6.6032E+01      2.090          7.8972E+02     20.000           1.013

  |---- MANEUVER LOAD DATA FOR CASE  27 AT TIME =    4.020E+00 SECONDS. ----|
QUADRANT ELEVATION =    8.004E+01
    NORMAL FORCE   MOMENT          STRESS 1       ALPHA          ALTITUDE
    AXIAL FORCE    LAT ACC, G'S    STRESS 2       ALPHA MAX      MACH #

     1.5516E+03    -1.9572E+04     -1.6831E+03     20.000        1.7841E+04
     2.3268E+02      4.953          1.5533E+03     20.000           1.538

  |---- MANEUVER LOAD DATA FOR CASE  28 AT TIME =    4.020E+00 SECONDS. ----|
QUADRANT ELEVATION =    8.029E+01
    NORMAL FORCE   MOMENT          STRESS 1       ALPHA          ALTITUDE
    AXIAL FORCE    LAT ACC, G'S    STRESS 2       ALPHA MAX      MACH #

     2.8950E+03    -3.6983E+04     -3.2278E+03     20.000        2.1850E+04
     6.0972E+02      9.934          2.8875E+03     20.000           2.342

  |---- MANEUVER LOAD DATA FOR CASE  29 AT TIME =    4.020E+00 SECONDS. ----|
QUADRANT ELEVATION =    7.997E+01
    NORMAL FORCE   MOMENT          STRESS 1       ALPHA          ALTITUDE
    AXIAL FORCE    LAT ACC, G'S    STRESS 2       ALPHA MAX      MACH #

     8.1326E+03    -1.0572E+05     -9.4514E+03     17.971        2.3752E+04
     2.5470E+03     30.000          8.0300E+03     20.000           4.724

  |---- MANEUVER LOAD DATA FOR CASE  30 AT TIME =    4.020E+00 SECONDS. ----|
QUADRANT ELEVATION =    7.997E+01
    NORMAL FORCE   MOMENT          STRESS 1       ALPHA          ALTITUDE
    AXIAL FORCE    LAT ACC, G'S    STRESS 2       ALPHA MAX      MACH #

     1.2245E+04    -1.6447E+05     -1.5662E+04      7.916        2.3752E+04
     7.3945E+03     30.000          1.1535E+04     20.000           9.446

    THERMAL STRESSES: CASE   1  WITH TIME =      4.01969 SECONDS.          MAX TENSILE STRESS IS    1.6810E+01 PSI.
```

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INDEX	RADIUS (IN)	TEMPERATURE (DEG.F)		|*********** STRESSES (PSI) HCOP	AXIAL	RADIAL **********|	MODULUS (PSI)		RADIAL EXPANSION (INCHES)
3	7.962400E-01	60.0	----	1.6809E+01	1.6810E+01	0.0000E+00	4.99249E+07	---	2.87850E-06
				9.6834E-01	1.3177E+00		4.99249E+07		
	8.290400E-01	60.0	----------	----------	----------	3.4908E-01	----------		2.98983E-06
				9.6831E-01	1.3176E+00		4.99248E+07		
2	8.454400E-01	60.1					4.99248E+07		
1	8.618400E-01	60.1	----	-2.1849E+01	-2.1849E+01	0.0000E+00	4.99248E+07	---	3.11565E-06

AXIAL EXPANSION = 2.41008E-06 INCHES, THE ELECTRICAL THICKNESS CHANGE = 9.53674E-07.

THERMAL STRESSES: CASE 2 WITH TIME = 4.01969 SECONDS. MAX TENSILE STRESS IS 7.9189E+01 PSI.

INDEX	RADIUS (IN)	TEMPERATURE (DEG.F)		|*********** STRESSES (PSI) HCOP	AXIAL	RADIAL **********|	MODULUS (PSI)		RADIAL EXPANSION (INCHES)
6	7.962400E-01	64.1	----	7.9186E+01	7.9189E+01	0.0000E+00	4.99196E+07	---	2.01812E-05
				4.5547E+00	6.2031E+00		4.99196E+07		
	8.290400E-01	64.5	----------	----------	----------	1.6439E+00	----------		2.09784E-05
				4.5547E+00	6.2031E+00		4.99191E+07		
5	8.454400E-01	64.6					4.99191E+07		
4	8.618400E-01	65.0	----	-1.0291E+02	-1.0290E+02	0.0000E+00	4.99191E+07	---	2.18439E-05

AXIAL EXPANSION = 1.68972E-05 INCHES, THE ELECTRICAL THICKNESS CHANGE = 2.38419E-05.

THERMAL STRESSES: CASE 3 WITH TIME = 4.01969 SECONDS. MAX TENSILE STRESS IS 1.9127E+03 PSI.

INDEX	RADIUS (IN)	TEMPERATURE (DEG.F)		|*********** STRESSES (PSI) HCOP	AXIAL	RADIAL **********|	MODULUS (PSI)		RADIAL EXPANSION (INCHES)
9	7.962400E-01	144.6	----	1.9126E+03	1.9127E+03	0.0000E+00	4.98141E+07	---	3.65518E-04
				1.1755E+02	1.5746E+02		4.98141E+07		
	8.290400E-01	152.7	----------	----------	----------	3.9853E+01	----------		3.79746E-04
				1.1753E+02	1.5743E+02		4.98024E+07		
8	8.454400E-01	156.8					4.98024E+07		
7	8.618400E-01	165.2	----	-2.5242E+03	-2.5242E+03	0.0000E+00	4.98024E+07	---	3.95633E-04

AXIAL EXPANSION = 3.06038E-04 INCHES, THE ELECTRICAL THICKNESS CHANGE = 4.56810E-04.

THERMAL STRESSES: CASE 4 WITH TIME = 4.01969 SECONDS. MAX TENSILE STRESS IS 3.4626E+04 PSI.

INDEX	RADIUS (IN)	TEMPERATURE (DEG.F)		|*********** STRESSES (PSI) HCOP	AXIAL	RADIAL **********|	MODULUS (PSI)		RADIAL EXPANSION (INCHES)
12	7.962400E-01	719.7	----	3.4623E+04	3.4626E+04	0.0000E+00	4.90252E+07	---	3.48224E-03
				4.3819E+03	5.1696E+03		4.90252E+07		
	8.290400E-01	827.2	----------	----------	----------	7.8412E+02	----------		3.60911E-03
				4.3531E+03	5.1352E+03		4.86815E+07		
11	8.454400E-01	881.0					4.86815E+07		
10	8.618400E-01	1025.3	----	-5.5930E+04	-5.5932E+04	0.0000E+00	4.86815E+07	---	3.76925E-03

AXIAL EXPANSION = 2.91562E-03 INCHES, THE ELECTRICAL THICKNESS CHANGE = 5.94435E-02.

THERMAL STRESSES: CASE 5 WITH TIME = 4.01969 SECONDS. MAX TENSILE STRESS IS 1.2936E+05 PSI.

(Note: Thermal stress results for cases 6 through 29 have been omitted from this sample.)

```
AXIAL EXPANSION =    1.55038E-03 INCHES,  THE ELECTRICAL THICKNESS CHANGE =    7.60269E-03.

    THERMAL STRESSES: CASE  30  WITH TIME =       4.01969 SECONDS.           MAX TENSILE STRESS IS    2.4893E+04 PSI.

                    RADIUS        TEMPERATURE        |*********** STRESSES  (PSI) ***********|        MODULUS          RADIAL EXPANSION
    INDEX            (IN)          (DEG.F)                 HOOP          AXIAL         RADIAL          (PSI)              (INCHES)

     185         7.778400E-01       1491.4      ----   2.4725E+04   2.4893E+04   0.0000E+00    1.63480E+07 ---    5.42637E-03
                                                       8.2806E+03   8.8727E+03                 1.63480E+07
                 7.988400E-01       1763.6      ------------------------------   4.2394E+02    ---------------    5.54698E-03
                                                       7.2608E+03   7.7787E+03                 1.42996E+07
     184         8.093399E-01       1899.7                                                     1.42996E+07
                                                      -1.5348E+04  -1.4897E+04                 1.42996E+07
                 8.198400E-01       2166.1      ------------------------------   3.5726E+02    ---------------    5.69758E-03
                                                      -3.5521E+03  -3.4450E+03                 3.39403E+06
     183         8.303400E-01       2516.6                                                     3.39403E+06
                                                      -3.5147E+04  -3.5397E+04                 3.39403E+06
                 8.408400E-01       2962.7      ------------------------------  -4.3945E-03    ---------------    5.95417E-03
                                                       0.0000E+00   0.0000E+00                 0.00000E+00
     182         8.513400E-01       3600.2                                                     0.00000E+00
     181         8.618400E-01       4429.0      ----   0.0000E+00   0.0000E+00   0.0000E+00    0.00000E+00 ---    6.67761E-03

AXIAL EXPANSION =    4.65938E-03 INCHES,  THE ELECTRICAL THICKNESS CHANGE =    5.46007E-02.
THE BORESIGHT ERROR FOR CASE   1 IS   4.406E-07
THE BORESIGHT ERROR FOR CASE   2 IS   1.101E-05
THE BORESIGHT ERROR FOR CASE   3 IS   2.110E-04
THE BORESIGHT ERROR FOR CASE   4 IS   2.746E-02
THE BORESIGHT ERROR FOR CASE   5 IS   7.704E-02
THE BORESIGHT ERROR FOR CASE   6 IS   1.078E-05
THE BORESIGHT ERROR FOR CASE   7 IS   7.737E-05
THE BORESIGHT ERROR FOR CASE   8 IS   6.753E-04
THE BORESIGHT ERROR FOR CASE   9 IS   2.452E-03
THE BORESIGHT ERROR FOR CASE  10 IS   2.293E-02
THE BORESIGHT ERROR FOR CASE  11 IS   4.199E-07
THE BORESIGHT ERROR FOR CASE  12 IS   2.351E-06
THE BORESIGHT ERROR FOR CASE  13 IS   5.119E-04
THE BORESIGHT ERROR FOR CASE  14 IS   3.186E-03
THE BORESIGHT ERROR FOR CASE  15 IS   2.076E-02
THE BORESIGHT ERROR FOR CASE  16 IS   9.638E-07
THE BORESIGHT ERROR FOR CASE  17 IS   5.728E-06
THE BORESIGHT ERROR FOR CASE  18 IS   1.115E-04
THE BORESIGHT ERROR FOR CASE  19 IS   1.544E-02
THE BORESIGHT ERROR FOR CASE  20 IS   7.034E-02
THE BORESIGHT ERROR FOR CASE  21 IS   4.462E-06
THE BORESIGHT ERROR FOR CASE  22 IS   4.408E-05
THE BORESIGHT ERROR FOR CASE  23 IS   4.465E-04
THE BORESIGHT ERROR FOR CASE  24 IS   2.288E-03
THE BORESIGHT ERROR FOR CASE  25 IS   2.010E-02
THE BORESIGHT ERROR FOR CASE  26 IS   1.071E-06
THE BORESIGHT ERROR FOR CASE  27 IS   1.008E-06
THE BORESIGHT ERROR FOR CASE  28 IS   1.753E-04
THE BORESIGHT ERROR FOR CASE  29 IS   2.678E-03
THE BORESIGHT ERROR FOR CASE  30 IS   1.923E-02
```

Appendix E

ERROR AND WARNING MESSAGES

In addition to the PL/I error messages that can occur due to faulty execution, several messages have been incorporated into the URLIM code that are generic to the radome limitations analyses. The PL/I messages that may occur are described in Ref. 2. The URLIM computational messages are listed below.

1. 'SUBROUTINE CYL2D: CALCULATED NODE # LARGER THAN ALLOWED (LASCAP), EXECUTION MAY BE FAULTY. CONTROL RETURNED TO MAIN PROGRAM'

   Cause
   A control value has been given to the two dimensional cylindrical network subroutine (CYL2D) for specifying the number of nodes within the section and a resultant node number has been computed that is larger than the control variable #NODES.

   Effect
   The subroutine is halted from further computation and the URLIM program continues. The thermal network that results may not be the one intended.

   Solution
   Either make #NODES larger so as to accommodate the number of nodes actually needed or reduce the control parameters to the two dimensional cylindrical subroutine.

2. 'SUBROUTINE TWOD: CALCULATED NODE # LARGER THAN ALLOWED (LASCAP), EXECUTION MAY BE FAULTY. CONTROL RETURNED TO MAIN PROGRAM'

   Cause
   Same as for message 1 above

   Effect
   Same as for message 1 above

   Solution
   Same as for message 1 above

3. 'THE FOLLOWING TEMPERATURE ENTRY WAS INCONSISTENT WITH THE FIRST SET OF PRESSURE ENTRIES. CHECK THE TABULAR INPUT' -- from subroutine READAIR.

Cause
In subroutine READAIR one set of temperature values input does not match the first set of temperatures (it is required that each set of temperatures input at each value of pressure be identical).

Solution
Examine the tabular input data and be sure it is consistent with the requirements.

4. 'THE FOLLOWING MACH # ENTRY WAS INCONSISTENT WITH THE FIRST SET OF ANGLE-OF-ATTACK ENTRIES. CHECK THE TABULAR INPUT' -- from subroutine READAFC.

Cause
In subroutine READAFC one of the Mach number entries did not match the first set of Mach number entries.

Solution
Examine the tabular input data and be sure it is consistent with the requirements.

5. 'ITERATION FOR T LOCAL IN SAERO BLOCK xxx HAS EXCEEDED xxx. T LOCAL = xxx, DELTA TL = xxx, AND ENERGY IMBALANCE = xxx' -- from subroutine SAERO.

Cause
The solution technique for calculating the local temperature behind the shock wave did not converge to the required limits. The value of TL that is printed out is used and the program continues.

Solution
Increase the number of allowed iterations and/or the tolerance values for the convergence. Check the velocity and altitude tables for anomolies and compare with expected

values. Check the Mach ratio and pressure ratio input tables.

6. 'ITERATION ON SURFACE NODE # xxx HAS EXCEEDED xxx, TSURF = xxx AND DELTA TSURF = xxx. HEAT IMBALANCE = xxx' -- from subroutine SAERO.

Cause
The surface energy balance routine has failed to find a solution within the thermal and heat flux tolerance levels input. The printed value of TSURF will be used.

Solution
Raise either the number of iterations or the convergence criteria, check input and calculated data for erroneous or excessively high heating rates, and check for inconsistent air, altitude and/or material property data. Check also that the temperatures are not beyond the extent of the air property tables.

7. 'AN ERROR IN THE COMCON DATA HAS BEEN ENCOUNTERED: CAPACITOR xxx OR CAPACITOR xxx HAS BEEN CONNECTED TO ITSELF THE COMCON DATA IS:

I	IA(I)	IB(I)	CT1(I)	CT2(I)
xx	xx	xx	xx	xx

THE SEARCH FOR A TEMPERATURE FOR RADIUS = xxx HAS CONTINUED' -- from subroutine SIGMA

Cause
The thermal network data contains an inconsistent nodal interconnection, namely a node has been specified as connected to itself. The error was detected while determining the contact temperature between nodes of different materials by the thermal stress routine.

Solution
Inspect the diagnostic information printed and correct the thermal model information. IA and IB are lists of the capacitor numbers that are connected through a contact resistance and CT1 and CT2 are the respective temperatures at either side of the contact surface.

8. 'THE COMCON DATA HAS BEEN SEARCHED & A TEM-

PERATURE VALUE FOR RADIUS = xxx HAS NOT BEEN FOUND. CONTROL HAS BEEN RETURNED TO THE SHTP FROM SUBROUTINE SIGMA'

Cause

In the nodal network data a contact resistance connection has been incorrectly specified or the input data (node number versus radius) is in error. Inspect these input data for proper assignments of interface locations.

Effect

The thermal stress calculation for this case is terminated and the main program continues.

9. 'ALL MODULUS COMPUTATIONS WERE ZERO, SIGMA TERMINATED ABNORMALLY' -- from subroutine SIGMA.

Cause

The elastic modulus for the entire wall thickness of a thermal stress case was computed to be zero. Either the temperatures are high enough to produce melting or the Modulus versus Temperature tables are in error.

Solution

In the cases where the temperatures are all past melting, this is actually a normal return from the thermal stress routine. Otherwise, inspect the Modulus versus Temperature input data for errors.

Effect

Control is given back to the main program and execution continues.

10. '***THE ABOVE GRADIENT IS NOT MONOTONIC. IT IS POSSIBLE THAT THE INTERPOLATION ROUTINE MAY HAVE TRUNCATED A PEAK***' -- from subroutine SIGMA.

Cause:

The distribution of temperature versus radius through a wall section is not monotonic; the interpolation routine (AIT) may have truncated the distribution.

Solution:
Inspect the tabulated temperature versus radius data for such a peak.

Effect:
Execution continues, the possibly truncated function is used.

11. 'INTEGRATION ROUTINE HAS EXCEEDED 20 ITERATIONS. THE RATIO = xxx' -- from subroutine SIGMA.

Cause
In calculating either elastic modulus or thermal strain values in the thermal stress routine, successive approximations to the value of an integral have not converged to within 0.5% in subroutine TRAP.

Solution:
The ratio of successive approximations is printed and can be examined for accuracy. If the ratio is unsatisfactory, the free thermal expansion and/or elastic modulus tables can be expanded or made smoother by adding entries.

Effect:
The program continues and uses the inaccurate value for the integral.

12. 'TIME STEP LESS THAN MINIMUM ALLOWED CRITICAL INDEX NO. = xx DELTIM = xxx' -- from subroutine STEP.

Cause:
The stability time step was calculated to be less than the minimum allowed by control variable MINSTEP.

Solution:
The thermal model must be altered so that the ratio of total capacitance to total conductance for the critical node is larger than the minimum allowable. Alternatively, a smaller allowable time step can be specified.

Effect:
The URLIM execution is halted.

13. 'STEADY STATE SOLUTICN HAS EXCEEDED xxx ITERATIONS.

THE NOT YET STEADY TEMPERATURES ARE:

[A list of nodes, temperatures and heat rates]

-- from subroutine STEADY.

Cause:

In the routine STEADY, the convergence criteria have not been met. In the message, the node number and current temperature are listed and the last correction to the temperature and the net heat flow for the node are also shown. Only the not yet converged nodes are printed (i.e., those nodes satisfying the convergence criteria are not printed in the above table). If PUNCH = 1 then all of the temperatures will be saved (as described in Appendix N) in spite of the incorrect solution. Before stopping the execution of the subroutine, whether convergence is met or not, a call to subroutine WRITE is made so that a printing of all of the temperatures is obtained.

It is possible that the solution may be intrinsically unstable with the initial guess as supplied. If this is true a random oscillation of the temperatures may result (with the iteration limit exceeded) or the temperatures will increase (or decrease) in magnitude until one of the temperatures becomes larger (or smaller) than can be represented by the computer on which the program is running. When this occurs an overflow or underflow error message will be printed and execution will be stopped without a printout of temperature. These underflow or overflow messages are not a part of the URLIM program.

Effect:

The program execution is halted.

Appendix F

THE READ ROUTINES

The READ routines are used by the URLIM program to read tabular data in EDIT format from card files. Each card file has the general format requirement of two comment cards followed by the tabular data. In many of the routines the identification number, the sequence of the arguments and the order of the data on the cards are important in specifying required data to other sections of the program. The data are required to be in specific column fields and are either in F- or E-format. The specific formats will be listed with each subroutine description. Each READ routine prints the data it reads on the output file SYSPRINT in a slightly reformatted manner. The first line of output serves to identify the specific subroutine and the identification number associated with the particular group of data, when appropriate. The next two lines simply echo the two comment cards that are input at the beginning of each table. The data table then follows.

READRK

Subroutine READRK is used in the main program of URLIM to read thermal transport and dielectric constant material properties. The identification number will associate the properties read in by READRK with the property code numbers used elsewhere in the program. The list of arguments for READRK must be in a specific order; i.e., READRK must be called as follows:

```
CALL READRK(ID#, RKTEMP, RHOCP, K, EMISS, DIEL,
            NPTS, FILENAME);
```

where:

ID#	is the material code for the properties which follow in the calling sequence (FIXED BIN);
RKTEMP	is the vector of Rankine temperatures and must be the second argument ((*) FLOAT

BIN), of dimension ≥ NPTS + 1;

RHOCP is the vector of density times specific heat values and must be the third argument ((*) FLOAT BIN), of dimension ≥ NPTS;

K is the vector of thermal conductivity data and must be the fourth argument ((*) FLOAT BIN), of dimension ≥ NPTS;

EMISS is the vector of IR emissivity factor values and must be the fifth argument ((*) FLOAT BIN), of dimension ≥ NPTS;

DIEL is a vector of dielectric constant values ((*) FLOAT BIN), of dimension ≥ NPTS;

NPTS is the number of tabular data cards read in by RADRK (FIXED BIN) (all the READ routines must have 2 comment cards ahead of the tabular cards); and

FILENAME is the name of the file from which the card images will be read (FILE).

The data on the card file named by FILENAME must be in the following format:

2 comment cards (160 characters) followed by:

Columns	Value
1-14	Values of temperature (°R), F-format;
15-29	Values of density times specific heat (Btu/ft^3-°R), F-format;
30-44	Values of thermal conductivity (Btu/ft-h-°R), F-format;
45-69	Values of IR emissivity, F-format;
60-69	Values of RF dielectric constant, F-format; and
70-80	Values of RF loss tangent, F-format.

If it is desirable to have the values of the thermal property variables set by some other method than reading the above described table, a call to subroutine READRK must still be made. In such a situation, the number of data points, NPTS, is set to zero and the call is made; this will serve to associate the variables in the calling sequence with the material identification number but no cards will be read from the file FILENAME.

It should be noted that READRK will store the value NPTS as the first entry to the independent variable, RKTEMP (unless NPTS = 0); this is consistent with the data management requirements of the interpolating routines used to extract values from the tables, (c.f. "Interpolation Techniques," Section 2 of Volume 1).

READFH

Subroutine READFH reads mechanical property data that is dependent on the Farenheit scale. The calling sequence and data table format are as follows:

```
CALL READFH(ID, FHTEMP, EMOD, NU, EXPANS, ENU,
            NPTS, FILENAME);
```

where the variable names are associated with the data table entries on the file FILENAME with the following format:

Item	Columns	Parameter and Format
ID	-	Table identifying number;
FHTEMP	1-14	Independent variable temperature (°F), (*) FLOAT BIN, dimensioned ≥ NPTS + 1, F-format;
EMOD	15-29	Values of elastic modulus (psi), (*) FLOAT BIN, dimensioned ≥ NPTS, E-format;
NU	30-44	Values of Poisson's ratio, (*) FLOAT BIN, dimensioned ≥ NPTS, F-format;

Item	Columns	Parameter and Format
EXPANS	45-59	Values of free thermal expansion (in./in.) FLOAT BIN, dimensioned ≥ NPTS, E-format;
ENU	-	Values of EMOD/(1-NU) calculated by the subroutine (i.e., not read) and printed on the output, FLOAT BIN, dimensioned ≥ NPTS;
NPTS	-	The number of tabular data cards read (recall that all the READ routines require two additional comment cards ahead of the data cards that are not counted as data cards); and
FILENAME	-	The name of a file that contains the NPTS + 2 card images read by READFH.

READFH stores NPTS as the first value of FHTEMP, and then stores the tabular values of temperature; therefore FHTEMP must be dimensioned ≥ NPTS + 1.

READCP

Subroutine READCP reads data from a file that describes part or all of the thermal interconnections between nodes. These interconnections may be via Fourier conduction within the same material, Fourier conduction between nodes of different materials, or radiation heat transfer. Any number of interconnections can be specified for any one node. The calling sequence for READCP is:

```
CALL READCP (FILENAME);
```

where FILENAME is the name of the file where the network data are written and has the FILE attribute. The data on the file FILENAME must be in EDIT format as follows:

Item	Columns	Value
1	1-4	Thermal node number, F-format;
2	10-19	Thermal node volume (ft^3), E-format;
3	20-29	Thermal material identification number, F-format;
4	30-39	The number of thermal interconnections for this node, F-format;
5	40-49	The node number of the first interconnecting node, F-format;
6	50-59	The area-to-length ratio of the thermal path between the centers of the two nodes (items 1 and 5 above) (ft), E-format;
7	60-69	The node number of the second interconnecting node, F-format;
8	70-79	The area-to-length ratio of the thermal path between the centers of the two nodes (items 1 and 7 above) (ft), E-format.

The number of cards read by READCP is not restricted but the end of the input is signalled by including a blank card at the end of the data.

The following example illustrates the use of the eight item data field in defining a node (No. 23) connected to two other nodes (Nos. 24 and 206):

```
23   4.8E-2   5.   2.   24.   2.301E0   206.   1.8E-1
```

This example entry shows node 23 as having a volume equal to 0.048 ft^3, being composed of material number 5, and having two interconnections: one with an A/L ratio to node 24 of 2.301 ft and an A/L ratio to node 206 of 0.18 ft.

For radiation heat transfer the interconnecting node numbers (item 5 cr 7) are input with minus signs

and the A/L ratios (either item 6 or 8) are interpreted as being the area times view factor between the nodes.

In order to describe a composite thermal interconnection (i.e., nodes of differing material identification numbers with a contact resistance at the interface) an alteration to the input conventions is required. In this case the items that are different than before are as follows:

Item	Columns	Value
3	20-29	A composite material code that is a three digit number identifying the material from the node (item 1) to the other node (item 5) with the contact resistance values represented as the center digit, F-format;
5	40-49	The node number of the compositely interconnected node, F-format;
6	50-59	The area-to-length ratio from the primary node center to the interface (ft), E-format;
7	60-69	The area of the interface (ft^2), F-format; and
8	70-79	The area to length ratio from the interface to the center of the connecting node (ft), E-format.

Note that the contact resistance values are assumed to have a unique material property code and must be input via a call to READRK. The values read in should be conductances (Btu/ft^2-h-°R) so that when multiplied by the contact area (Item 7 above) a true conductance (Btu/h-°R) is achieved. (In some cases the contact resistance is assumed small and a very large number (1.0E9) can be input in Item 7 along with any arbitrary material code for the interface so that a large conductance for the interface is achieved.)

The following example will show the form of a composite connection description:

23 4.8E-2 452. 1. 24. 2.3E0 20.6 2.3E0

This shows node 23 (the first item) connected to node 24 (the fifth item) through a composite or contact connection (by virtue of the three digit third item). The first digit (4) of this composite material code is for node 23, the second digit is for the conductance of the contact, and the third digit is for the compositely connected node, 24. The path length from node 23 to the contact is item 6 (2.3 ft), the contact area is item 7 (20.6 ft^2), and the path length to node 24 from the contact is item 8 (2.3 ft).

In the general case where one node must be connected to more than two other nodes, or must be connected to several nodes via composite connections, a one-card entry offers insufficient room for all the data. In such cases the number of connections entry (Item 4) is set to some number larger than the total number of active thermal nodes. The rest of the entries are then set as necessary according to the conventions mentioned above. A second card entry will then be required whose first entry (Item 1) will be the same value as the previous number-of-connections entry. This convention is then seen to be an indirect addressing scheme wherein the number-of-connections entry refers to a card number where more interconnection data may be found. This technique may be used to any number of levels and is obviously terminated when a standard number-of-connections is encountered (i.e., a value of 1 or 2). It is very important that the indirectly addressed cards have Item 1 entries larger than the highest active capacitor number. To insure proper allocation of storage for all of the network information the proper call should be made to subroutine STORE (c.f. Appendix I). To illustrate the use of the indirect addressing scheme consider the following two entries:

23	4.8E-2	452.	101.	24.	2.3E0	20.6	2.3E0
101	4.	2.	22.	1.6E0	32.	3.6E0	

In this example the card for node 23 has its number-of-connections entry set to 101; the next card has for its "node" number the value 101 and will be unders-

tood to contain further connection data for node 23, namely that nodes 22 and 32 connect via material 4 to node 23 with the appropriate conduction paths.

Another situation that often arises is when a thermally anisotropic material is used. In such cases the thermal conductivity is different in different spatial directions. The URLIM program considers only two-dimensional anistropy and therefore two sets of thermal conductivity data are needed. To indicate this the material property entry (Item 3) will be a two-digit number, the first of which indicates the material code for the connection described by Items 5 and 6 and the second digit will apply to the connection described by Items 7 and 8. In this way two thermal conductivities can be applied for the two different thermal path directions.

Any of the above entry conventions for network description can be combined in any manner on indirect address cards.

READAIR

Subroutine READAIR must be used to read in the temperature- and pressure-dependent properties of air when aerodynamic heating is to be used. The subroutine is invoked by the following CALL sequence to read values of pressure, temperature, enthalpy, Prandtl number, specific heat ratio, viscosity, and compressibility:

```
CALL READAIR(#PRES, #TEMPS, CPRES, CTEMP, CENTH,
             FILENAME);
```

where:

#PRES is the number of different pressure values for the bivariant data (FIXED BIN),

#TEMPS is the number of different temperature values for the bivariant data (FIXED BIN),

CPRES is a conversion factor that will be multiplied with each pressure value read (this number represents the conversion

	required to obtain lbf/ft^2 from whatever units the pressure values are supplied in) (FLOAT BIN),
CTEMP	is a similar factor for obtaining °R from the the temperature values as supplied (FLOAT BIN),
CENTH	is a similar conversion factor for obtaining Btu/lbm-°R from the enthalpy values as supplied in the data (FLOAT BIN),
FILENAME	is the variable naming the file where the data are to be found (FILE).

The cards read by READAIR must have the following data in the following format:

Two cards used for comment followed by data cards:

Columns	Variable and Format
1-10	Pressure, F-format;
11-20	Temperature, F-format;
21-30	Enthalpy, F-format;
31-40	Prandtl number, F-format;
41-50	Specific heat ratio, F-format;
51-60	Viscosity (lbm/ft-s); and
61-70	Compressibility, F-format.

The two independent variables must be in monotonically increasing order; i.e., all values at the lowest pressure must be first followed by the next largest pressure, etc., and all cards for the same pressure value must have the temperatures in increasing order. The routine will expect (#PRES times #TEMPS) plus two cards to be in the file FILENAME.

The values read are stored in several external variables whose management is cf no direct concern to

the user. The only requirement is that if the routine SAERO is used for aerodynamic heating then READAIR must be called to read the air properties.

READAL

READAL is a subroutine that reads from a file the altitude-dependent properties of the atmosphere, namely the ambient temperature, pressure, speed of sound, and effective space temperature as functions of altitude (expressed in feet). READAL is called as follows:

```
CALL READAL(#ENTS, CPRES, CTEMP, FILENAME);
```

where:

#ENTS is the number of entries to be read in,

and the other values have the same definitions as for READAIR but apply to the data read by READAL. The data format for READAL is tabular Fixed Point (F-format), 15 column widths preceded by two comment cards:

Columns	Value
1-15	Values of altitude, the independent variable for this table (ft);
16-30	Values of ambient temperature;
31-45	Values of ambient static pressure;
46-60	Values of the speed of sound (ft/s); and
61-75	Values of the effective temperature of space for radiation relief (°R).

The data read must be in increasing order with respect to altitude and will be stored in external variables outside of the user's awareness. The later use of subroutine SAERO requires the reading of the altitude table by routine READAL.

READFL

Subroutine READFI has the function of reading in the Mach and pressure ratio data, as functions of Mach number. These data are required by SAERO to determine the local flow conditions at the station of interest on the flight body so that heat transfer can be calculated. The READFL subroutine is invoked by the following statement:

```
CALL READFL(ID#, MACH#, MACHRAT, PRAT, VGRAD, NPTS,
        FILENAME);
```

where:

ID# identifies the table of data that are read (FIXED BIN);

MACH# is the list of Mach numbers (the independent variable) ((*) FLOAT BIN);

MACHRAT is the list of Mach ratios that exist from the free stream to the local condition on the body ((*) FLOAT BIN);

PRAT is the list of pressure ratios that exist from the free stream to the local condition on the body ((*) FLOAT BIN);

VGRAD is the list of velocity gradient terms that exist at the stagnation point of a body in flight (in cases where stagnation point heating is not required, these values, though read in, will not be used ((*) FLOAT BIN); and

NPTS is the number of data points in the table to be read (FIXED BIN).

The data on the file FILENAME should have two comment cards followed by NPTS tabular data cards:

Column	Variable and Format
1-14	MACH#, F-format;
15-29	MACHRAT, F-format;
30-44	PRAT, F-format; and
45-59	VGRAD, F-format.

If any VGRAD data entry is left blank, a value of 1 will be assumed for that entry.

READAFC

The READAFC routine reads the bivariant aerodynamic force coefficient data when aerodynamic loads are to be calculated by subroutine AERLOAD. The data read are the Mach number and angle of attack dependent values of missile normal force coefficient, radome axial and normal force coefficient, and axial location of center of pressure. The routine is invoked as follows:

```
CALL READAFC(#ALPHA, #MACH, FILENAME);
```

where:

#ALPHA is the number of angle of attack entries in the tabular data (FIXED BIN);

#MACH is the number of Mach number entries in the tabular data (FIXED BIN); and

FILENAME is the name of the file where the data will be found.

The data on file FILENAME should include two comment cards followed by the data cards in monotonically increasing order of angle-of-attack and Mach number as follows:

Columns Variable and Format

Columns	Variable and Format
1-13	Angle of attack (deg), F-format;
14-26	Mach number, F-format;
27-39	Normal force coefficient of the missile, F-format;
40-52	Normal force coefficient of the radome alone, F-format;
53-65	Axial force coefficient of the radome alone (i.e., without base drag effects), F-format;
66-78	Axial lccation of the center of pressure, normalized to the total length of the radome, F-format.

The data read are stored in external variables whose management is of no direct concern to the user.

READTM

The READTM subroutine can be used to read in tables of time-dependent data. The routine, like many of the other READ routines, has general utility for reading arbitrary data but must be used in a specific form if the aerodynamic heating routine SAERO is used. For such cases the routine READTM is called as shown:

```
CALL READTM(ID, TIME, ALT, VEL, QRAD, DUM, DUM,
     NPTS, FILENAME);
```

where:

ID — is the trajectory number which will be used later by SAERO (FIXED BIN);

TIME — the list of times during the flight (s) ((*) FLOAT BIN);

ALT	is the list of altitude values (ft) ((*) FLOAT BIN);
VEL	is the list of freestream velocities (ft/s) ((*) FLOAT BIN);
QRAD	is a list of independently supplied heat flux values that may be applied to the SAERO surface (Btu/ft^2) ((*) FLOAT BIN);
DUM	is a suitably dimensioned dummy variable or a valid variable for use by another subroutine called in the main program; and
NPTS, FILENAME	are as before except that they apply to the data read by READTM.

The data on file FILENAME should be of the following form:

Two comment cards followed by NPTS tabular data cards with the following format:

Columns	Variable and Format
1-9	TIME, F-format;
10-19	ALT, F-format;
20-29	VEL, F-format;
40-49	QRAD, F-format; and
50-59	DUM or any other variable, F-format.

The first variable, TIME, must be a list of at least NPTS + 1 length because, as with other READ routines, the READTM routine places the value NPTS as the first entry to TIME and then the actual time values follow.

If it is desired not to read the trajectory data for a subsequent SAERO call via READTM then a call to READTM must still be made but NPTS is set to zero. This null CALL statement will cause the identification number

to be correctly associated with the variable names in the argument list but no access will be attempted to the file FILENAME.

READSG

The READSG routine reads data that describes the cylindrical geometry and temperature information required by the cylindrical thermal stress routines, SIGMA and SIGMET. The information is in the form of tables of thermal node number versus radius plus an indication of the finite difference mesh size for the thermal stress solution. The subroutine is called as follows:

```
CALL READSG(ID#, RADII, XINTR, IND, MAT, NREGS,
        NHTP, FILENAME);
```

where (c.f. Fig. 11 fcr nomenclature conventions):

ID# — identifies the table of values (FIXED BIN);

RADII — is a list of radii (in.) at which temperatures will also be given ((*) FLOAT BIN);

XINTR — is a list of radii (in.) that define the boundaries of the finite difference mesh through the cylinder's thickness (there should be NREGS + 1 such radii) ((*) FLOAT BIN);

IND — is a list of thermal node numbers that correspond one-to-one with the entries in RADII above ((*) FIXED BIN);

MAT — is a list of mechanical property code numbers that are used by subroutine SIGMA and correspond one-to-one with the radius entries of RADII above (the numbers serve to indicate which material properties exist through the thickness of the cylinder) ((*) FIXED BIN);

NREGS	is the number of subdivisions that are to be made through the thickness of the cylinder (FIXED BIN);
NHTP	is a flag for indicating whether or not the data read are to be used (by the routine SIGMA) in conjunction with a heat transfer program run (subroutine SIGMA may be executed either with temperatures supplied by the user (NHTP=0) or with temperatures supplied by the heat transfer calculations of the SHTP (NHTP=1)) (FIXED BIN); and
FILENAME	is the file that the data will be read from (FILE).

For NHTP=0 (indicating user supplied temperatures and SIGMA run independently of the SHTP) the following data must be on the file FILENAME:

Two comment cards followed by a group of data cards arranged in increasing order of radius. These cards are of two types, either region boundary or temperature (all values are in F-format).

Region boundary cards have this format:

Columns	Value and Variable Name
45-54	Region boundary radius (in.) (XINTR); and
55-64	Region boundary temperature (°F).

Temperature cards have the following format:

Columns	Value and Variable Name
1-15	Radius value (in.) (RADII));
16-30	Temperature value (°F); and
31-40	Mechanical property identification number (MAT).

The first and last cards must be Region boundary cards. Region boundary and temperature cards may have

the same value of radius but the two types of data must be on separate cards.

For NHTP=1 (indicating routine SIGMA being used in conjunction with SHTP routines that will calculate temperatures) the tabular data entries, arranged in increasing order of Radius values, will be of the following two types:

Region Boundary:

Columns	Value and Variable
40-54	Region boundary radius (in) (XINTR).

Temperature:

Columns	Value and Variable
1-15	Value of radius (in.) (RADII);
16-25	Thermal node number from the thermal network (IND); and
26-35	Mechanical property identification number (MAT).

As before, the first and last entries must be region boundary cards. Temperature and region boundary cards may have the same value cf radius but the two types of information must not appear on the same card.

The arangement of cards just described is designed to allow the geometry data to be input in a way that resembles the geometry being modeled; i.e., the cards defining stress region boundaries and those defining temperatures at various radii are interleaved in increasing radial order. The only other convention is that the first and last cards must be stress boundary cards even if temperatures are to be defined at these radii as well. Recall that region boundary cards and temperature cards may have the same value cf radius, if desired.

Appendix G

UNIFORM GEOMETRY ROUTINES

Subroutines are available in the SHTP library that may be used to calculate automatically the nodal volumes, numbers, and interconnection information for uniform thermal grids. The routines can be used for one- or two-dimensional grids in rectilinear (Cartesian) or cylindrical coordinates.

TWOD

Subroutine TWOD is used for describing Cartesian nodal networks and is called as follows (refer to Fig. 8 for symbol conventions):

```
CALL TWOD(ID#, Z, XS, NX, YS, NY, IPROP, FRSTNOD,
          SIDE1, SIDE2, SIDE3, SIDE4);
```

where:

ID#	is an identification number for the two-dimensional region being generated (FIXED BIN);
Z	is the depth dimension to the nodal grid, the z-direction (ft) (FLOAT BIN);
XS	is a list of x-direction thicknesses to be used in the nodal break-up ((*) FLOAT BIN) (if XS is dimensioned to 1, then the single value will be taken as the total x-direction thickness and the variable NX will be taken as the number of evenly spaced divisions that will be made within the x-direction thickness);
NX	is the number of x-direction divisions that are to be used (FIXED BIN);

YS	is the list of y-direction thicknesses to be used in the nodal break-up ((*) FLOAT BIN) (if YS is dimensioned to 1 then the single value will be taken to indicate the total extent of the region in the y-direction and NY will be understood to be the number of equally spaced divisions that will be made);
NY	is the number of y-direction divisions that are to be used (FIXED BIN);
IPROP	is the thermal property identification number for the single material that will be used in the two dimensional region (FIXED BIN);
FRSTNOD	is the node number of the first node in this region (FIXED BIN),
SIDE1-SIDE4	are flags, either 0 or 1 that determine the type of thermal path length that will be used for the four surfaces of the 2-D region (FIXED BIN).

The routine TWOD is seen to have two modes of operation, one to allow the specification of an arbitrary mesh break-up or the other to allow a uniform one. The choice is determined by the dimensions of the two lists XS and YS. All length values are to be in feet. The routine prints out a table of results that shows node number, volume, material identification, the number of interconnecting nodes, and the node numbers and thermal path lengths for the interconnecting nodes. The output is annotated as being from the TWOD routine and gives the region identification number.

CYL2D

The CYL2D routine calculates the volumes and appropriate A/L path lengths for two-dimensional cylindrical regions of arbitrary depth. The routine is called as follows (refer to Fig. 7 for nomenclature):

CALL CYL2D(ID#, Z, RADII, NT, ROUT, THETAS, NTH,

IPROP, FRSTNOD, SIDE1, SIDE2, SIDE3, SIDE4);

where:

ID#	is the region identification number (FIXED BIN);
Z	is the region depth (ft) (FLOAT BIN);
RADII	is a list of radial spacings that will determine the node thicknesses, measured from the outer radius inward (ft) (if RADII is dimensioned to 1 then the single value will be taken to be the total radius thickness and NR will be the number of evenly spaced divisions that will be used in the nodal descriptions) ((*) FLOAT BIN);
NR	is the number of radial divisions (FIXED BIN);
ROUT	is the outer radius of the cylindrical region (ft) (FLOAT BIN);
THETAS	is the list of angular (circumferential) divisions that will be used to describe the nodal network (deg) (if THETAS is dimensioned to only 1, then the single value will be taken to be the total angular extent of the region and NTH will specify the number of equally spaced divisions that will be used) ((*) FLOAT BIN);
NTH	the number of circumferential divisions in the regions (FIXED BIN);
IPROP	is the thermal property identification number for the single material in the region (FIXED BIN);
FRSTNOD	is the number of the first node in the region (FIXED BIN); and
SIDE1, SIDE4	are flags (either 0 or 1) indicating the type of thermal path calculations that

will be made at the four region surfaces (FIXED BIN).

The routine prints out the results of its calculations in the form of a table with an entry for each node, as follows: node number, volume, material identification, the number of interconnecting nodes, and the node number and thermal path lengths.

CYL3D

The CYL3D routine is used much the same as CYL2D except that the region being modeled is assumed to be three-dimensional; i.e., the depth dimension, Z, is allowed to be divided into sections. The calling sequence is:

```
CALL CYL3D (NREG, Z, NZ, RADII, NR, ROUT, THETAS,
            NTH, IPROP, FRSTNOD, SIDE1, SIDE2, SID
            SIDE5, SIDE6, XTOFEET);
```

where:

Z — is a list of axial (z-direction) spacings to be used in defining the grid (as with the other lists of spacings this list may contain NZ numbers that will specify the z-direction grid spacings or, if dimensioned to 1, will specify the total axial extent of the region, and NZ will be taken to be the required number of evenly spaced divisions;

NZ — is the number of z direction spacings;

SIDE5, SIDE6 — are the code numbers (either 0 or 1) for determining the type of connection length to be used for the additional surfaces (in reference to Fig. 7, these surfaces are the front (SIDE5) and back (SIDE6)); and

XTOFEET — is a conversion factor for obtaining the units of feet from the units as supplied for Z, ROUT, and RADII (this term will be multiplied times each value of Z, ROUT,

and RADII and the results will be assumed to be in feet).

The CYL3D routine will, as required, store connection information for nodes with three interconnections via the indirect address method discussed in Appendix F, READCP. In this technique, the interconnection matrix, XCAP, must be dimensioned large enough to allow the appropriate number of extra entries (refer to the description of subroutine STORE, Appendix H).

The parameter XTOFEET represents an improvement over CYL2D, and will be included therein upon the next revision to that routine. Further, the conversion implied by this term will not change the numbers supplied as arguments; i.e., the conversions will be strictly internal to the routine CYL3D and, upon return from the routine, the values of Z, ROUT, and RADII will not have been altered.

The results of CYL3D's calculations will be printed in a manner similar to that of CYL2D with the addition that the indirect address entries to XCAP will be included.

Appendix H

INITIALIZATION ROUTINES

In order to execute a heat transfer program using the SHTP library, certain values must be set and the proper storage must be allocated for certain variables. Because the dynamic storage allocation feature of the PL/I language has been widely incorporated into the SHTP library, a specification of the storage requirements must be made. Essentially, the amount of storage needed for variables is a direct function of the number of nodes in the thermal network. The routines SET and STORE accomplish the allocation and initialization of many of the needed variables.

STORE

Subroutine STORE allocates storage according to its arguments and is called by the following statement:

```
CALL STORE(#CAPS, XCAPLIM, TYPRUN);
```

where:

#CAPS is greater than or equal to the number of thermal nodes in the current problem (FIXED BIN);

XCAPLIM is the number of locations to be reserved in the XCAP array; note that XCAPLIM should be ≥ #CAPS, (FIXED BIN) (in problems where multiple interconnections between nodes are specified via indirect card entries to the READCP routine, XCAPLIM must be set to the value of the largest such indirect card number (c.f. READCP, Appendix F));

TYPRUN indicates the type of run being made according to the following values:

1 Normal run, transient heat transfer problems;

2 Steady state analyses, iterative approach;

3 Special run, used for certain ablation subroutines;

4 Steady-state analyses via a matrix solution technique.

The TYPRUN parameter is normally set to 1 but must be set to the other values according to the type of analysis desired. Appendix N of this volume explains the usage of the two steady state analyses, and the other code (TYPRUN=3) is for a program described in Ref. 4 and will not be applicable to any of the discussions in this report. All of the variables allocated by STORE are initialized to values of zero.

SET

Subroutine SET is used to initialize the nodal temperatures and to set the starting and ending times for the transient heat transfer solution. The routine is called as follows:

```
CALL SET (STARTIM, STOPTIM, TINIT, #SET, SETNODES,
     SETTEMPS);
```

where:

STARTIM is the starting time for the transient heat transfer calculations (s) (FLOAT BIN);

STOPTIM is the final time for the transient calculations (s) (the heat transfer program will stop when this time is reached) (FLOAT BIN);

TINIT is the temperature that all of the thermal nodes will be set to (^oR) (FLOAT BIN);

#SET is the number of nodes that will be set to temperatures other than the initial temperature (TINIT) (FIXED BIN);

SETNODES is the list of node numbers that will be set to specific initial temperatures ((*) FIXED BIN); and

SETTEMPS is the corresponding list of specific initial temperatures for the list SETNODES ((*) FLOAT BIN).

All of the nodes listed in SETNODES will be initialized to the corresponding values in SETTEMPS. Zero is a valid value for #SET, in which case the arguments SETNODES and SETTEMPS may be null variables (dimensioned to 0).

Appendix I

BOUNDARY CONDITION ROUTINES

After the physical model of the structure being analyzed is established, the boundary conditions the body is subjected to must be specified as a function of time. There is provision in the SHTP library to allow specified temperature and heat flux boundary conditions as well as the effects of aerodynamic heating. These routines are discussed below.

FORCER

Subroutine FORCER allows for the specification of temperature histories for selected thermal nodes. The routine is called as follows:

```
CALL FORCER (NODES, TEMPS, TIMES);
```

where:

NODES — is the list of thermal node numbers that will be constrained to the specified temperature history ((*) FIXED BIN); and

TEMPS, TIMES — are the schedule of temperatures and times, respectively, that will be applied to the thermal nodes ((*) FLOAT BIN).

The TIMES array must have as its first entry the number of time-temperature pairs that there are. Also, a value of zero for any entry to NODES will cause any subsequent entries not to be forced to follow the specified temperature history.

FLUX

Subroutine FLUX is used to impose a specified heat flux to a list of thermal nodes. The routine is called as follows:

CALL FLUX (N, NODES, AREAS, VIEWS, ALPHA, TEMP, QDOT, TIME);

where:

N	is the number of nodes in the list NODES to be affected by the heat flux (FIXED BIN);
NODES	is the list of thermal nodes that will be affected ((*) FIXED BIN);
AREAS	is the list of surface areas that will be exposed to the heat flux (ft^2) in one-to-one correspondence with the entries in NODES, ((*) FLOAT BIN),
VIEWS	is the list of view factors that will be applied to the surfaces listed in AREAS ((*) FLOAT BIN),
ALPHA, TEMP	are the lists of absorptivities and temperatures (°R) that describe the absorptive properties of the surfaces (each (*) FLOAT BIN); and
QDOT, TIME	are the lists of heat flux and time values that define the heat flux history to be applied to each node in NODES (Btu/ft^2-h) (each (*) FLOAT BIN).

The value of heating rate that will be applied to each of the nodes in NODES will be the product of the following terms: the surface area (AREAS); the view factor (VIEWS); the absorptivity of the surface, evaluated at the surface temperature; and the heat flux at the current time. Note that the end result of this series of multiplications is a heat rate term expressed in Btu/h. With appropriate input by the user, the flux routine can be used to simulate another boundary con-

dition, namely internal heat generation. In this case the QDOT values should be in units of Btu/ft^3-h and the AREAS values should be the volumes of the nodes listed in NODES. The net result in the heat transfer program is the same: a heat rate (Btu/h) is added to the appropriate node.

The first entries to the independent variables TEMP and TIME must be the number of total data entries in the lists ALPHA and QDOT, respectively. This is the standard convention used for the READ routines and the interpolation routines that must use the data.

SAERO

The subroutine SAERO is used to determine the surface temperature at any point on a structure exposed to high speed fluid flow. The heat transfer calculations use the Reynolds analogy and the reference enthalpy method of Eckert to derive heat transfer coefficients. (Refer to "Heat Transfer -- Convection" in Section 1 of Volume 1 for a complete discussion of the techniques used). It will suffice at this point to say that the SAERO routine performs a heat balance across the heated surface and numerically determines the surface temperature. This temperature is then provided to the rest of the heat transfer program essentially as a boundary condition. The routine is called as follows (Refer to Fig. 9 for nomenclature):

```
CALL SAERO(ID, #CAPS, SNODES, RNODES, AREA, REFLEN,
           SHAPE, D_L, RECRIT, VIEW, TRAJID,
           FLOID, TLIM, CLIM, ITLIM);
```

where:

ID — is the identifying number for the case in point (FIXED BIN);

#CAPS — is the number of individual surface nodes that are in this aero block and are therefore affected by the same body station parameters (FIXED BIN);

SNODES, — are, respectively, the lists of surface

RNODES	node numbers and connecting capacitor numbers used in modeling the structure ((*) FIXED BIN),
AREA	is a list of surface areas (ft^2) for each of the SNODES ((*) FLOAT BIN);
REFLEN	is a list of reference lengths (used in the Reynolds number calculation) for each of the SNODES (ft) ((*) FLOAT BIN);
SHAPE	is a code for determining the kind of aerodynamic heating calculations that will be done. The following codes apply: 1 flat plate correlations, 2 cone flow correlations, 3 pipe flow correlations, 4 stagnation point (two-dimensional), and 5 stagnation point (three-dimensional) (FIXED BIN);
D_L	is a list of values used in determining the heating rate for pipe flow and is the ratio of the diameter to the length-downstream-from-opening for each of the SNODES; if SHAPE is not equal to 3, then these values have no effect ((*) FLOAT BIN) (when considering pipe flow it should be remembered that REFLEN must be set equal to the hydraulic diameter);
RECRIT	is the value of the transition Reynolds number between laminar and turbulent flow (FLOAT BIN);
VIEW	is the single view factor to be applied to each SNODE equally for the input radiation, QRAD, described above for READTM, (FLOAT BIN),
TRAJID	is an identifying number that numerically matches an identification number for some

READTM statement that will contain values of velocity and altitude versus time (FIXED BIN),

FLOID	is an identifying number that corresponds numerically with an identification number for some READFL statement wherein the appropriate values of local to freestream Mach No. ratio, local to freestream pressure ratio, and velocity gradient factor were read in versus freestream Mach No. (FIXED BIN);
TLIM, QLIM, ITLIM	are the parameters for judging the convergence of the two iteration processes carried out by SAERO (in each of these iterations the calculated temperature must be within TLIM of the true temperature solution and the resulting energy balance must have a residual of not more than QLIM. Further, no more than ITLIM iterations will be allowed. If any of the convergence criteria are not met, a pertinent message is printed and the execution will continue).

Appendix J

HEAT TRANSFER CALCULATIONS

The heat transfer program calculates the transient thermal response of a heated structure via a forward marching, finite difference technique. The details of the finite difference solutions can be found in Section 2 of Volume 1. The subroutines that perform this task are described in the following paragraphs.

CAPCON

The routine CAPCON uses the nodal network information stored in the external array XCAP to calculate the temperature dependent values of thermal capacity (Btu/ft^3-^{o}R) for each node and the sum of all the conductances for each node (Btu/^{o}R-h). These values are the essential coefficients in the finite difference equations and are used later by subroutine STEP. CAPCON is called as follows:

```
CALL CAPCON;
```

There are no arguments to CAPCON because all the essential parameters (material identification numbers, conduction paths, volumes, etc.) have been organized previously and stored in the appropriate external variables via calls to READRK, READCP, CYL2D, TWOD, etc.

STEP

Subroutine STEP has two essential functions: to determine the stability time step and calculate the change in nodal temperatures from one time point to the next. Refer to "Transient Heat Conduction" in Section 2 of Volume 1 for a discussion of the finite difference equations and the stability criterion. Subroutine STEP

is called as follows:

CALL STEP (MINSTEP, MAXSTEP);

where:

MINSTEP is the smallest permissible time step for the calculations (FLOAT BIN), and

MAXSTEP is the maximum permissible time step that will be used (FLOAT BIN).

If a calculated time step is less than MINSTEP the program will terminate with an error message. If a calculated time step is larger than MAXSTEP, then the time step is set to MAXSTEP and execution continues.

Appendix K

MATERIAL RESPONSE ROUTINES

There is a collection of subroutines that have been devised to couple with the SHTP so as to simultaneously calculate selected secondary material responses of the structures being analyzed. These secondary responses include thermal stresses for cylindrical geometries, boresight errors of radar through a monolithic wall radome, and stresses in a radome due to aerodynamic load.

SIGMA, SIGMET

These two routines calculate thermal stresses for cylindrical geometries according to a finite difference technique developed by Rivello (Ref. 3, and "Thermal Stress" in Section 1 of Volume 1). SIGMET differs from SIGMA in that it performs the additional calculation of the electrical thickness change of the wall segment. The thermal stresses are calculated by making a thick-wall cylinder assumption. The cylinder can be made up of several different materials and may be assumed either fully restrained from axial expansion or free to expand axially. The electrical thickness calculations are based on calculations of the wall's physical thickness change and the temperature coefficient of the dielectric constant versus temperature. The complete calculation of boresight errors is accomplished with the help of subroutine MOBSER, whose use will also be described.

SIGMA

The routine SIGMA calculates thermal stresses in cylinders in the hoop, axial, and radial directions. It requires lists of temperature versus radius and elastic property data versus temperature to do so. These data

can be read in and made available to SIGMA via routines READSG and READFH. The calling sequence is:

```
CALL SIGMA(ID, NREG, B, R, IND, MAT, TEMP, XMOD,
          DELTAL, XNU, PO, PN, TNOSTRS, ENDR,
           PLTCODE);
```

where:

ID is an identifying number (FIXED BIN);

NREG is the number of regions or subdivisions that will be made through the wall for the finite difference solution (FIXED BIN);

B is the list of NREG+1 radius values that define the region boundaries (in.) ((*) FLOAT BIN);

R is the list of radius values at which temperatures will be specified (in.) ((*) FLOAT BIN);

IND is the list of thermal network capacitor numbers that will be assumed to exist at each respective radial position indicated in R, above ((*) FIXED BIN);

MAT is the list of material indexes (property code numbers) that will identify the material properties that exist at each radial position, R, above (these indexes are keyed to identification numbers used by READRK and READFH) ((*) FIXED BIN);

TEMP, XMOD, DELTAL are two-dimensional arrays of temperature (°F), elastic modulus (psi), and free thermal expansion (in./in.) for the materials used in the cylindrical section. The first subscript position of each of these arrays contains the material identification number (specified by MAT) and the second subscript position contains the particular property data (each (*,*) FLOAT BIN);

XNU is the value of Poisson's ratio that will be used in the calculation (FLOAT BIN);

PO, PN are the internal and external pressures, respectively, that may exist on the cylinder (psi) (FLOAT BIN);

TNOSTRS is the temperature at which the cylinder will be assumed stress free (°F) (FLOAT BIN);

ENDR is a flag indicating the assumed end restraint for the cylinder; e.g.,

1 rigidly restrained ends, and

0 ends free to expand (FIXED BIN); and

PLTCODE is a pseudo-node number that, if nonzero, will be used to store the maximum tensile stress that exists in the wall at each time the data are stored (this number is used as an index to the array of thermal node temperatures so that if plots are used (via subroutine PLOTTER), thermal stress histories may be plotted, if desired) (FIXED BIN),

The routine SIGMA may or may not be used with the SHTP. To insure the proper execution in either case, routine READSG should be used to set up the proper data items. When used with the SHTP, SIGMA will execute only at the times listed in the arguments to subroutine WRITE.

SIGMET

Subroutine SIGMET is the same as subroutine SIGMA except for the additional calculation of the electromagnetic (EM) wave thickness change of the wall segment. This calculation requres one additional piece of information, namely the incidence angle of the EM wave. This is input in the argument list as the variable named PHI in the example below of the calling sequence:

```
CALL SIGMET(ID, NREG, B, R, IND, MAT, TEMP, XMOD,
            DELTA, XNU, PO, PN, TNOSTRS, ENDR, PHI,
            PLTCODE);
```

where all the variables have the same precise definitions as with SIGMA except:

PHI — is the EM wave incidence angle (deg) (FLOAT BIN).

The calculation of electrical thickness change is essential for the monolithic boresight error slope calculations performed in subroutine MOBSER, described next. All of the comments pertinent to routine SIGMA apply to routine SIGMET with the addition that the material property codes now apply to the thermal properties (read in by READRK) as well as the mechanical properties (read in by READFH).

MOBSER

Subroutine MOBSER uses data from routine SIGMET and from its own arguments to calculate a boresight error slope (deg/deg) for a radar beam through a monolithic radome wall. The calculation is based on an empirical relationship among the parameters mentioned and applies to von Karman shapes. The routine is called as follows:

```
CALL MOBSER (ID, FREQ, SEP, PLOTID);
```

where:

ID — is a case identifying number and keys the routine back to a previous CALL to SIGMET wherein the electrical thickness change was calculated (FIXED BIN);

FREQ — is the radar frequency of the incident beam (Hz) (FLOAT BIN);

SEP — is the effective phase center separation of the radar antenna aperture (in.) (FLOAT BIN); and

PLOTID a psuedo-node number used to store the boresight error slope and the electrical thickness change values at each time point. This number and the next highest integer (i.e., PLOTID+1) are to index the array of thermal node temperatures and therefore must not be the numbers of actual network nodes. A value of zero for PLOTID will cause no such storage to take place. Later, if the routine PLOTTER is used to store or plot the nodal temperatures, these indexes can be used to generate boresight error slope and electrical thickness change histories.

The variable ID joins the calculation of electrical thickness change to the other parameters and routine SIGMET must be called before routine MOBSER.

AERLOAD

Subroutine AERLOAD is used principally for radome analyses, wherein the stresses due to aerodynamic pressure and maneuver loads at the missile-radome attachment are required. The routine uses the radome and missile aerodynamic force coefficients read by READAFC, and is keyed via the argument variable TRAJID to a trajectory definition read in by a READTM statement. The routine is called as follows:

```
CALL AERLOAD(ID, L, RB, T, CMSTA, RHO, WM, YDPDOT,
             ALTHDOT, ALTHDDT, TRAJID, PLOTID);
```

where:

ID is an identifying number (FIXED BIN);

L is the length of the radome from tip to attachment point (in.) (FLOAT BIN);

RB is the radius of the radome at the attachment point (in.) (FLOAT BIN);

T is the thickness of the radome wall at the attachment point (in.), (FLOAT BIN);

CMSTA is the missile body station that locates the missile's center of mass (in.), (FLOAT BIN);

RHO is the density of the radome material (lbm/ft^3) (FLOAT BIN);

WM is the weight of the missile (lbf) (FLOAT BIN);

YDDOT is the maximum possible maneuver acceleration normal to the axis of the missile (ft/s^2) (FLOAT BIN);

ALTHDOT is the maximum possible rate of change of angle of attack for the missile (deg/s) (FLOAT BIN);

ALTHDDT is the maximum possible acceleration of angle of attack for the missile (deg/s^2) (FLOAT BIN);

TRAJID is an identifying number for the trajectory information needed by AERLOAD (this number must match an identification number for a call to routine READTM elsewhere in the program) (FIXED BIN); and

PLOTID is a psuedo-node number used for storing the maximum te stress calculated by AERLOAD at each time point (this number must not correspond to an active thermal node in the network; a value of zero will cause no storage to take place).

Part of the data that will be expected in the trajectory tables is the maximum permissible angle of attack. These data are allowed to be variable with time and is therefore implicitly dependent on altitude (c.f. Appendix F, subroutine READTM). If the specified lateral acceleration, YDDOT above, requires an angle of attack greater than that allowed, then the maximum angle of attack is used and the resultant lateral acceleration is accepted. The AERLOAD routine executes only at the times listed in the argument to subroutine WRITE.

Appendix L

OUTPUT ROUTINES

There are two kinds of output available from the SHTP -- printed results and CalComp plots. The printed results come mainly from the individual subroutines that perform the respective computations. The nodal network temperatures are obtained from the subroutine WRITE which keys other subroutines to print their results. Subroutine WRITE has two forms -- one that prints a well formatted, compact output of the temperatures and another that can be used for debugging purposes that prints the temperatures and other important program variables. The CalComp plotting routines are set up so that plots of temperatures versus time can be made either during a program run or later, after the run. The specific details of these capabilities are discussed under each routine name below.

WRITE

Subroutine WRITE is used to indicate when the printed output should be made. The calling sequence is:

CALL WRITE (PRNTIMS);

where:

PRNTMS is a list of times (s) at which the printed output will be made ((*) FLOAT BIN).

If PRNTIMS is dimensioned to 1 then the single value placed therein will be taken as an increment to be successively applied to the starting time of the program to achieve an evenly spaced sequence of printouts.

If the value of PRNTIMS(1) is negative, then the printed output will be made after every time step in the program. This option should be carefully used only for

debugging because considerable unnecessary output can result.

Within routine WRITE is a one-bit flag called PRINTIT which is accessible by every routine in the SHTP that generates printed output. Each time routine WRITE prints its own output, the PRINTIT bit is set to indicate to the other routines to print as well. In this way, the schedule of times in the argument PRINTIMS regulates the execution and/or printout of the other computational routines.

Subroutine WRITE can be used to obtain the nodal temperature data in a different format than the one described and shown in Appendix C. In addition to the node numbers and temperatures, program variables C (nodal capacitance), H (nodal conductance), and Q (net nodal heat flow) are printed. Additionally, if there are composite conduction paths specified in the program then the information pertinent to these connections is also printed. The routine uses more paper than the standard WRITE routine, but can be helpful in debugging. To obtain this alternate output feature, simply supply the first value of PRNTIMS as 999.

LIMIT

Subroutine LIMIT was devised strictly for the radome limitations work and is used to save pertinent data from an URLIM run for plotting by the routine LIMPRNT, described below. The calling sequence for LIMIT is:

```
CALL LIMIT(ID, FHMAT, RKMAT, TIMEID, MELTNODE,
           TITCARD);
```

where:

ID — is an identifying number and will later show up as the limit case number (FIXED BIN);

FHMAT — is the mechanical property data number for the radome material and was assigned via an earlier call to routine READFH (FIXED

BIN);

RKMAT is the thermal property ID number for the radome material and was assigned via an earlier call to routine READRK (FIXED BIN);

TIMEID is a list of trajectory identification numbers that will serve to define the trajectories over which the limit case will be performed; these identification numbers must have been previously assigned via calls to routine READTM ((*) FIXED BIN);

SIGID is a list of thermal stress case numbers from subroutine SIGMET that will be used to determine thermal stress failure points along the trajectories listed in TIMEID (a one-to-one correspondence of the values listed in SIGID and TIMEID will be made to determine which stress case goes with which trajectory; the thermal stress identification numbers will be used to identify boresight error case numbers as well since the electrical thickness change calculations are performed by the same routine -- SIGMET) ((*) FIXED BIN);

LODID is a similar one-to-one list of aerodynamic load calculation indexes that identify previous calls to routine AERLOAD ((*) FIXED BIN);

MELTNODS is a two-dimensional array of thermal node numbers that will select the nodes to be monitored for melting. The first subscript position corresponds one-to-one with each trajectory in TIMEID and the second subscript position lists all of the nodes susceptible to melting ((*,*) FIXED BIN); and

TITCARD is an 80-character string that will be used to identify the limits plot that is made by LIMPRNT (CHARACTER (80)).

Summary Note

For each trajectory listed in TIMEID above, there will be: a stress case identification number, a load case identification number, and a list of node numbers subject to melting. The boresight error case numbers will be assumed the same as the stress case numbers.

Subroutine LIMIT uses the identification number information supplied via its arguments to monitor the level of the radome material's responses as compared to maximum allowable values. In the case of thermal stresses the maximum tensile thermal stress for each stress case is stored in the EXTERNAL variable MAXSTRS which is an (*) FLOAT BIN variable and is indexed with the identification numbers in either routine SIGMA or SIGMET (i.e., the variable SIGID above). The LIMIT routine compares the values of MAXSTRS (SIGID) with the maximum permissible tensile stress stored by the user in the external variable MOR. MOR is an (*) FLOAT BIN array indexed with the identification numbers from routine READFH (i.e., variable FHMAT above).

The boresight error rate values are stored in the external variable BSER which is an (*) FLOAT BIN array indexed with the identification numbers from routine SIGMET (i.e., variable SIGID above). The values of bore sight error slope that are calculated during the program execution are compared to a value stored by the user in the EXTERNAL variable MAXBSER. MAXBSER is an (*) FLOAT BIN variable that is indexed by the material identification numbers of routine READRK (i.e., the variable RKMAT above).

In the case of aerodynamic and maneuver loads at the attachment point in the radome, the EXTERNAL variable AERSIG ((*,2) FLOAT BIN) keeps track of the two principle stresses, one at the upper section and one at the lower section of the radome (c.f. Fig. 10). The first subscript position of AERSIG is indexed by the identification numbers in routine AERLOAD (i.e., variable LODID above.)

In the case of melting, the thermal nodes listed in MELTNODS are monitored with respect to the last tem-

perature entry in the thermal property tables read in by the appropriate READRK statement. In other words, the last temperature supplied in each of the thermal property tables is taken to be the melt temperature for that material.

The LIMIT routine monitors the specified cases for each trajectory and makes note of the time at which the maximum allowable value is exceeded. The program performs this monitoring in two modes -- in the first mode as soon as any one of the four limits is reached, the time is noted and further monitoring along that trajectory is halted; in the second mode, all of the limits are monitored all of the time up to the end of the trajectory. The mode selection is accomplished by specifying a control value for the external variable MINRUN: 0 implies all the limits all the time, and 1 implies only the first limit.

At the end of the heat transfer program run (when the time variable has passed the STOPTIM value in subroutine SET), LIMIT writes its accumulated limits data on two files. The first is called LIMPLT and is a sequential record file used to preserve the numerical results for later use. The other file is SYSPRINT and the data is presented in graphical form. This later printed output is generated via an internal call to routine LIMPRNT. The numerical file LIMPLT must have a data definition card describing it, in the JCL for the execution of the job. Figure 6 contains an example of a suitable JCL card. The file is a record file; i.e., the data are written in a machine format that has not been converted to a character format. The data organization and a discussion of how to generate limits plots from the saved data after an URLIM run are given in Appendix O. Examples of the printer plots generated by LIMPRNT are given in Figures 4 and 5.

PLOTTER

The PLOTTER routine is used for saving and plotting the nodal temperature data of an SHTP run. The nodal temperatures are plotted versus time and can be arranged in any format, drawn to any scale and annotated with any phrase. The routine is designed so that plots may be made concurrent with a run of the SHTP or separately, after an SHTP run. This latter feature allows for plot

selection after the printed results of an analysis have been obtained and reviewed. The routine is general and allows a degree of flexibility.

The calling sequence is:

```
CALL PLOTTER(TIMES, DDNAME, FORMAT, TMPSCAL, TIM-
         SCAL, TMPINIT, TIMINIT, TITLE);
```

where:

TIMES is a list of times (s) during the run of a main program at which the variables will be plotted (if it is required to have the values plotted at every time step in the SHTP then the value of TIMES(1) should be negative; if the plotting frequency is to be at regular intervals of time, then TIMES should be dimensioned only to 1 and the value of the plotting interval desired placed in TIMES(1)) ((*) FLOAT BIN);

DDNAME is a character string variable of type CHARACTER(7) which names a DD card in the JCL of the job being run. This DD card describes the file onto which the values to be plotted will be written.

If the plot is being made concurrent with the running of the SHTP then the file described on the DD card may be a temporary file and deleted after the job is completed. In general, however, the plot file may be saved and used again to plot other variables if desired. The sample program in Appendix A uses a DD card named PLOT to identify the temperature file. For a temporary file the DD card should be:

```
//DDNAME DD UNIT=TEMP,
//       SPACE=(3500,(10,10),RLSE),
//       DISP=(NEW,DELETE)
```

To save the plot file use:

```
//DDNAME DD DSN=group.username.xxxx,
//     UNIT=SAVE,
//     DISP=(NEW,CATLG),
//     SPACE=(3500,(10,10),RLSE)
```

FORMAT — is a two-dimensional array of integers ((*,*) FIXED BIN) that indicates what variables are to be plotted on which plots. The extent of the first dimension of FORMAT is the number of different plots being made, and the extent of the second dimension is the maximum number of variables plotted on any one plot (i.e., if FORMAT was dimensioned FORMAT (x,y), there would be x different plots and a maximum of y variables plotted on any one plot.) FORMAT then contains x lists (rows) of numbers, each list containing y numbers. The actual numerical entries to FORMAT specify node or capacitor numbers to be plotted; i.e., the numbers are used to reference the temperature vector T in the SHTP. An entry of zero in FORMAT causes no curve to be drawn. Furthermore, an entry of zero at the start of any row in FORMAT will cause no plotting for the entire row. If an entry to FORMAT is negative, then a plotting symbol will be plotted with each data point on that curve. If ABS(FORMAT (x,y)) = 999, then a 2- by 2-in. grid will be drawn by the routine. If this is used with plain plotting paper, then the resultant plot is suitable for formal presentation. An example is shown in Fig. L-1. If FORMAT (1,1) = 0, then no plotting at all will be done and the plotting values will be stored on the file DDNAME;

TMPSCAL — is a list of scaling values to be used on the vertical axis of each plot. There should be, therefore, at least x entries to TMPSCAL. The numerical entries specify the number of data units (ft, deg, psi, etc.) per inch of plotting paper on the vertical axis. TMPSCAL has the attributes (*) FLOAT BIN. An additional feature of the plotting capability is affected through the TMPSCAL variable: when FORMAT (1, 1) ≠ 0 and any entry to TMPSCAL is negative, then a list of normalization factors will be read in from the SYSIN file in list format. These values will be

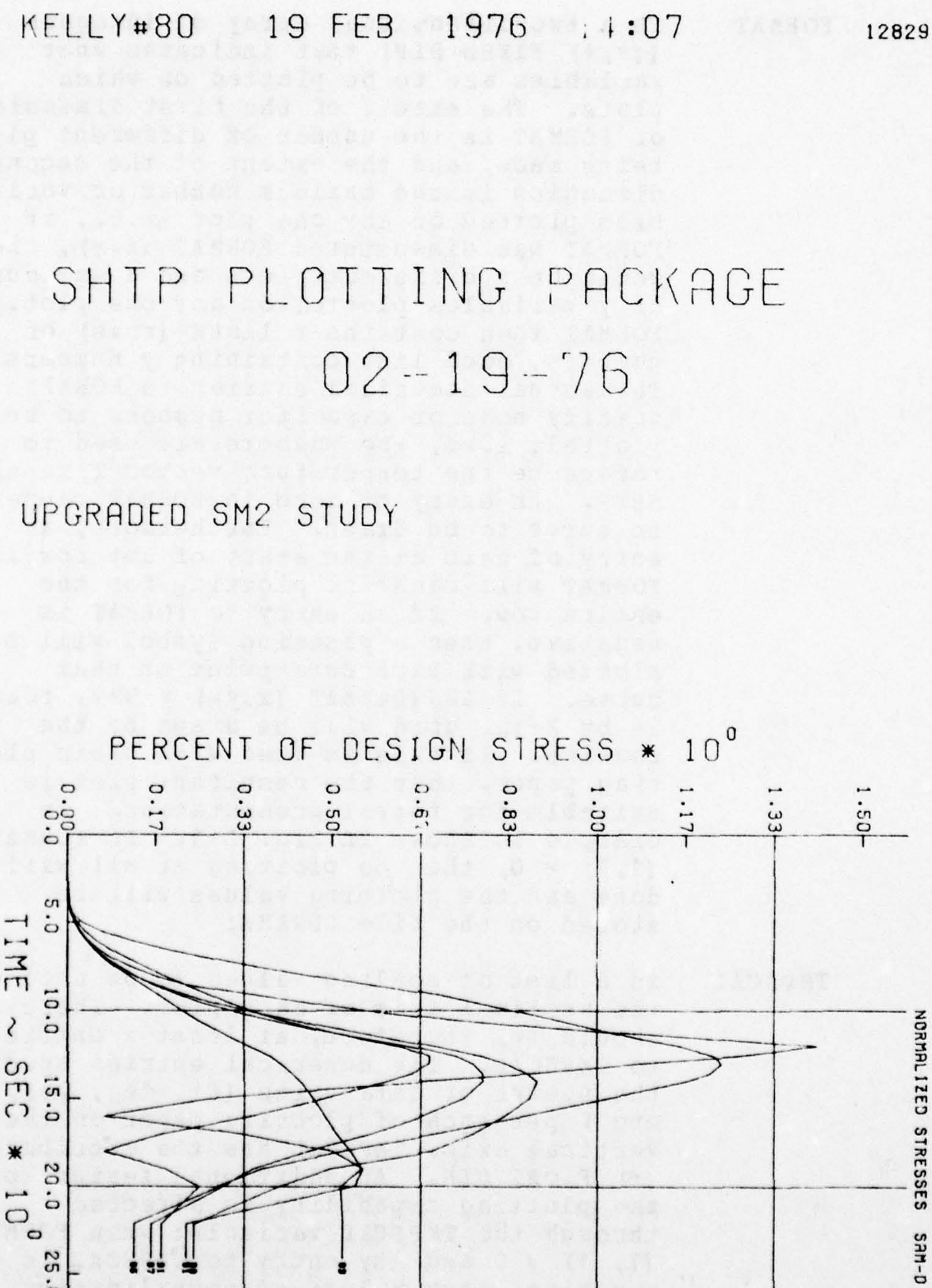

Fig. L-1 Sample CalComp Plot Output of URLIM Program Parameters

divided into each value for each curve on the plot that the negative value of TMPSCAL would have been associated with. Further, the scale value used along the vertical axis of the plot will be in accordance with the absolute value of the value of TMPSCAL. In other words, if a plot (numbered n) is to be made and the corresponding value for the vertical scale (TMPSCAL(n)) is negative, then the SYSIN file is read for y numbers in LIST format. Each of these y numbers will be used to normalize the respective thermal node values when plotted. The ith curve on plot number n is the set of values T(FORMAT(n,i)) divided by the ith normalization factor read in because of the negative value of TMPSCAL(n);

TIMSCAL is a constant value specifying the scale to be used for the horizontal (time) axis. It is a constant and therefore the same for each plot. The value is the number of seconds per inch of plotting paper to be used for the time axis (FLOAT BIN);

TMPINIT is a list of initial values for the beginning of each of the vertical axes. There must be at least x entries to TMPINIT, which has attributes (*) FLOAT BIN);

TIMINIT is a constant value specifying the initial value to be used as the origin for the horizontal (time) axis (FLOAT BIN);

TITLE is a character variable into which may be stored commentary phrases for labeling and identifying the plots. TITLE is an array dimensioned to 2 and each subscript refers to a character string no longer than 40; i.e., TITLE has the attributes TITLE(2) CHARACTER(40) VARYING. TITLE(1) appears at the beginning of the plot along with constant identifying phrases (described in Fig. L-2) and at the top of each plot. TITLE(2) appears along the vertical axis of each plot. If the value -999 is supplied as the last value in any row of

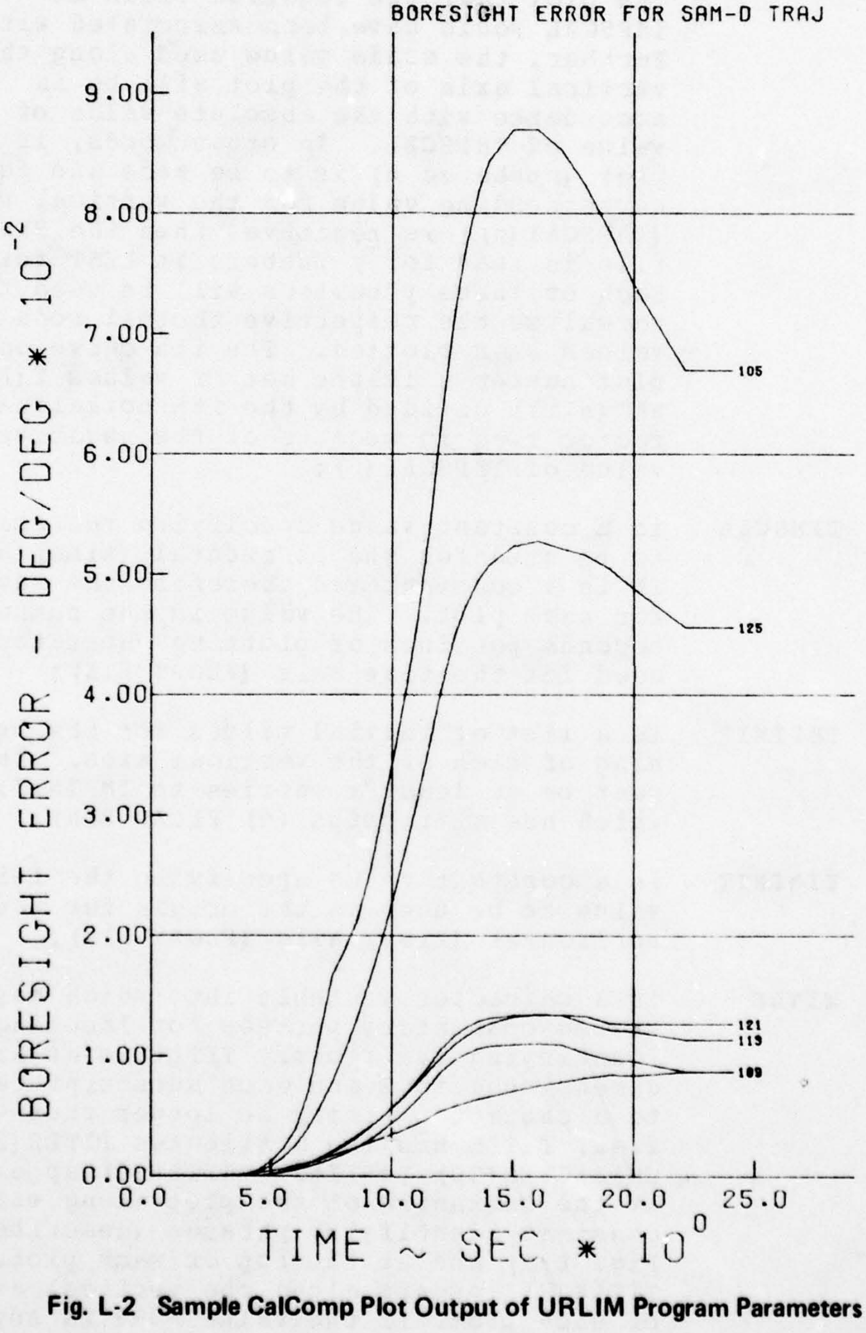

Fig. L-2 Sample CalComp Plot Output of URLIM Program Parameters

FORMAT then the values of TITLE will be changed by reading new values from the SYSIN file. In particular, when plots are being made, (FORMAT(1,1) ≠ 0) and FORMAT (n,y) = -999 then the SYSIN file will be read for two character strings, in LIST format, each not longer than 40 characters.

The primary purpose of routine PLOTTER is to store all of the temperature data (the T vector) on the file DDNAME at each time pcint requested. If FORMAT(1,1) is not equal to zero then a plot will also be made; for this case, in addition to the SHTP subroutine library, the library containing the CalComp software must be made available and a DD card of the following type must be used:

```
//PLOTAPE DD UNIT=(TAPE9,,DEFER),
//        VOL=SER=PLOTp,LABEL=(,BLP),
//        DCB=(RECFM=F,LRECL=480,DEN=3)
```

where the "p" indicates the priority desired for the off-line running of the plot; "O" is for overnight, "N" is normal, "Q" is quick(i.e., twice the normal charge), and "E" is emergency (i.e., three times the normal charge).

PLOTEM

The routine that actually performs the plotting functions is named PLOTEM and is called by PLOTTER on the condition mentioned above: FORMAT (1,1) ≠ 0. When a plot is required after an SHTP run, then a small program calling PLOTEM must be executed. This miniprogram need only have the required variable declarations and a single call to PLOTEM, as follows (c.f. Appendix O):

```
CALL PLOTEM(DDNAME,FORMAT,TMPSCAL,TIMSCAL, TIM-
        PINIT,TIMINIT,COUNT);
```

where:

COUNT is the number of time points at which the temperature data is stored during the SHTP

AD-A057 459 JOHNS HOPKINS UNIV LAUREL MD APPLIED PHYSICS LAB F/G 17/9
URLIM - A UNIFIED RADOME LIMITATIONS COMPUTER PROGRAM. VOLUME 2--ETC(U)
APR 78 R K FRAZER N00017-72-C-4401
UNCLASSIFIED APL/JHU/TG-1293B NL

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run. This number is printed by PLOTTER at the end of an SHTP run as follows:

"PLOTTER FILE 'DDNAME' HAS BEEN COMPLETED. TEMPERATURES AT xxx TIME POINTS WERE RECORDED.", where xxx is the value required for COUNT (FIXED BIN); and

DDNAME is a CHARACTER(7) VARYING string that identifies the DD card (file) that describes the data set on which are stored the temperatures that were saved from a previous execution of the SHTP. In Appendix O, DDNAME has the value 'PLTFILE'.

The other variables in the calling sequence are as described above for PLOTTER.

When each of the x plots have been completed, a message is printed by PLOTEM;

"PLOT NUMBER n HAS BEEN COMPLETED."

indicating a normal execution of the routine.

Figures L-1 and L-2 show sample plots in which six capacitor numbers (105, 109, 113, 117, 121, and 125) are plotted. The first figure (Fig. L-1) shows the identifying header and the date the data were stored. Also TITLE(1) is printed. The plot itself shows the time axis label and the user supplied label (TITLE(2)) adjacent to the vertical axis along with the various scale annotations. At the end of each separate curve is the node number for the particular capacitor. Figure 13 shows the plot resulting from the formal plotting option ABS(FORMAT (x,y)) = 999).

Thermal stresses can be plotted via the PLOTTER/PLOTEM routines by setting the PLTCODE argument in routine SIGMA (or SIGMET) appropriately and then using that same numerical value as an entry to the FORMAT array.

Summary Note

The routine PLOTTER will record all of the thermal node and psuedo-node values on the file named by DDNAME.

If, at the end of an SHTP run, various nodes have been selected by entries in FORMAT (i.e. FORMAT(1,1) ≠ 0) then plots will be generated via an internal CALL to PLOTEM. The routine PLOTEM proceeds as follows: first, the data saved on the file named by DDNAME are read in; for each entry to TMPSCAL that is negative, a list of y normalization values are read in LIST format from SYSIN; after all such values are read, values for TITLE will be read from SYSIN only if the value -999 is input as the last value to a row in FORMAT. (Note that if the value of the last number in the last row of FORMAT (i.e., FORMAT(x,y)) is -999 then formal plots will be made and two new TITLE values will be read for the x-th plot; also, the values ±999 occuring in FORMAT will not cause a curve to be drawn for node 999, rather the value has the same effect as a zero.) The reading of new titles, if indicated, occurs just prior to the generation of the plotting commands for each plot. The sequence is then:

1. All data read from file identified by DDNAME,

2. all normalization factors read in as indicated by values in TMPSCAL,

3. normalization factors applied to appropriate values,

4. new values of TITLE read in as indicated by the last entries to rows in FORMAT, and

5. Plotting commands written out to PLOTAPE file.

Appendix M

UTILITY ROUTINES

Many of the routines in the SHTP deal numerically with functions that are represented in tabular form. As a result, considerable use is made of interpolation (table look-up). Several varieties of interpolation have been developed for particular types of data and are embodied in so-called utility routines. The usage of these routines should not be of direct concern to the user. However, it could prove helpful if the user were aware of the assumptions and techniques employed as errors often occur due to inconsistencies in the tabular data used by these routines. A detailed discussion of the interpolation techniques is given in "Interpolation Techniques," Section 1 of Volume 1.

DECIDE

The routine DECIDE is the most frequently called routine of all the SHTP subroutines. It is used to provide values of thermal conductivity and heat capacity as they vary with temperature for each node in a given problem as well as many other variables. It is a linear interpolator with a serial table look-up procedure; i.e., it searches serially through the table of independent variable values until it finds two entries that bracket the given value of independent variable; the returned value is then linearly determined. DECIDE is a function subroutine (i.e., it may appear to the right of an equal sign in any algebraic expression); for example:

```
Y = DECIDE (KNOWNX, DEP, INDEP);
```

where:

Y	is the variable whose value will be determined by the routine DECIDE (FLOAT BIN);
KNOWNX	is the known value of the independent

variable (FLOAT BIN);

INDEP is the tabular list of independent variable values whose first entry (INDEP (1)) is the number of dependent variable values (#N); INDEP must therefore be dimensioned at least to (#N+1) ((*) FLOAT BIN);

DEP is the tabular list of dependent variable values ((*) FLOAT BIN) that correspond with the data values INDEP(2) through INDEP(#N+1).

If INDEP is dimensioned only to 1, then the corresponding single value stored in DEP will be the value returned. This option is made available to facilitate the inclusion of constants where functional values are normally required.

PIF1

The PIF1 routine is a linear interpolator similar to DECIDE except it expects the data in its arguments in a slightly different format:

Y = PIF1 (KNOWNX, INDEP, N, DEP);

where the variables are as previously defined for DECIDE and N has the same value as #N previously used and has the FIXED BIN attribute. PIF1 does not require the number of entries in the table (#N) to be stored as the first number in INDEP so that the values in INDEP correspond 1 to 1 with the values in DEP for this routine.

AIT

Subroutine AIT uses a modification of Aitken's method to interpolate tabular data. The routine is called as follows:

Y = AIT (KNOWNX, INDEP, N, DEP);

and is used exactly as PIF1. AIT is used primarily by the SIGMA/SIGMET routines to interpolate temperature versus radius tables and produce smooth curve fits.

PIF1D

PIF1D is a linear interpolator that also returns the derivative of the dependent variable with respect to the independent variable. The routine is used as follows:

CALL PIF1D (DEP, INDEP, KNOWNX, Y, DYDX);

with DEP and INDEP being the dependent and independent variable tables ((*) FLOAT BIN); KNOWNX being the known value of the independent variable and Y being the required dependent variable so that Y =f(KNOWNX). DYDX will be the slope of the function at the value KNOWNX; i.e., DYDX = f'(KNOWNX). Y and DYDX are FLOAT BIN variables. As with DECIDE, PIFID requires the independent variable list to begin with the number of data entries and, therefore, be dimensioned to at least #N+1.

LINLOG

The LINLOG routine is a linear-logarithmic interpolator that takes the logarithm of the dependent variable tabular values, interpolates linearly between these logarithmic values and then returns the antilog of the interpolated value. This procedure might also be represented as:

Y = EXP (PIF1 (KNOWNX, INDEP, N, LOG(DEP)));

The routine is called as follows:

Y = LINLOG (INDEP, DEP, KNOWNX, N);

where the variables have the definitions as previously stated. Note that LINLOG does not require the number of

data table entries (N) to be stored as the first word in INDEP.

The algorithm in LINLOG makes use of some assumptions that the user should be aware of. If the interpolation requires the use of a tabular value of DEP between +1 and -1 then a strictly linear interpolation is used. For DEP table values less than -1, the logarithmic interpolation is carried out using absolute values and the returned value will have the correct sign. The routine automatically limits the absolute values of entries in DEP to less than 10^{43}. It is generally good practice to include values in DEP and INDEP that cover DEP values near +1, -1, and 0 if the function represented by DEP is both positive and negative.

BIVLID

BIVLID is a linear interpolator of dependent variables that vary with two independent variables. The routine, according to a control value, will also return the partial derivatives. (The name is an acronym formed from: BIVariate Linear Interpolator with Derivatives.) In this case y = f(X1,X2) and the derivatives are either with respect to X1 or X2. The routine can also perform an inverse interpolation; i.e., given a value of the dependent variable and a value of one of the independent variables, the corresponding value of the other independent variable will be returned. The routine is called as follows:

```
CALL BIVLID(FOFXS, X1, X2, X1VAL, X2VAL, Y, DYDX,
            FLAG);
```

with:

FOFXS a two-dimensional array of dependent variable values ((*,*) FLOAT BIN),

X1 a vector of independent variable values ((*) FLOAT BIN),

X2 the other vector of independent variable values ((*) FLOAT BIN),

X1VAL a given value of the independent variable represented by X1 (FLOAT BIN),

X2VAL a given value of the independent variable represented by X2 (FLOAT BIN),

Y the required interpolated value, (FLOAT BIN),

DYDX the returned value of the partial derivative as required by the value of FLAG (FLOAT BIN), and

FLAG a control variable to indicate which partial derivative is required and whether the interpolation is inverse or not (FIXED BIN). FLAG can have the values +1, -1, -2, or +2.

If FLAG is negative then inverse interpolaticn is performed and the returned value will be: X1VAL if FLAG was -1, or X2VAL if FLAG was -2.

If FLAG is positive then normal interpolation is performed and Y is returned. In each case, the partial derivative returned is determined by the absolute value of FLAG: If ABS (FLAG) = 1 then DYDX is the partial with respect to X1 If ABS(FLAG) = 2 then DYDX is the partial with respect to X2.

It must be noted that the first subscript of FOFXS has corresponding entries in X1 and the second subscript position of FOFXS has corresponding values in X2; i.e., FOFXS(I,J) is the value of the dependent variable at X1(I) and X2(J).

BIVLLID

BIVLLID is exactly the same as BIVLID except that the linear-logarithmic interpolation method described above for LINLOG is used (i.e., the routine is a

BIVariate Linear-Logarithmic Interpolator with Derivative). All of the arguments and options described for BIVLID are the same fcr BIVLLID; the calling sequence is identical, only the interpolation algorithm used by the routine is different.

TRAP

The routines SIGMET and SIGMA make use of the routine TRAP to perform integrations of elastic modulus and thermal expansion data as functions of radius. TRAP uses a trapezoidal integration algorithm and is called internal to SIGMA and SIGMET as follows:

```
Y = TRAP(ORDER, FOFT);
```

where

ORDER	indicates the weighting factor in the equation shown below (FIXED BIN), and
FOFT	is the temperature dependent variable ((*) FLOAT BIN).

If FOFT is a function of temperature (FOFT = f(T)) and the temperature (T) is a function of radius (T = g(R)), then the returned value from TRAP is:

$$y = \int_a^b R^n f(g(R))\; dR$$

where the limits of integration, a and b, and the other functional tables required are all variables that are internal to the SIGMA/SIGMET routines and do not enter into the calling sequence.

CROSIM

The solution to the finite difference equations used in SIGMA/SIGMET are obtained in subroutine CROSIM. The routine is called, internal to SIGMA/SIGMET as

CALL CROSIM (MAT, N);

where

MAT is a coefficient matrix for the set of equations being solved and is dimensioned to (N+2) by (N+2) ((*) FLOAT BIN (53)), and

N is equal to 2 times the number of regions the cylindrical wall segment is divided into (FIXED BIN).

The solution vector is returned in the (N+1)th column of the matrix, MAT. The solutions obtained in the CROSIM routine are done in double precision to eliminate significant round-off error that can occur otherwise.

Appendix N

STEADY-STATE TEMPERATURE ROUTINES

A series of subroutines has been developed that allow the determinaticn of the steady-state temperatures in bodies modeled by the SHTP subroutine library. The routines employ a Gaussian elimination technique that is iterated to achieve the nonlinear solution to the steady-state heat balance equations for each node in the network being considered. Details of the solution technique are given in Section 2 of Volume 1.

STEADY

The routines involved with the steady-state solutions have been purposely designed to be completely compatible with the existing SHTP structure. The user who wants a steady-state analysis instead of a transient analysis must take three basic steps:

1. Change the TYPRUN argument in Subroutine STORE to a 4, (c.f. Appendix H),
2. Replace the "CALL STEP" statement to a "CALL STEADY" statement as shown below.
3. Include the apprcpriate subroutines during the LINK-EDIT step of the job assembly, also described below.

In the main program used to describe the particular problem being analyzed, the CALL STEP statement is replaced by a CALL STEADY statement of the following syntax:

```
CALL STEADY(#ITERS, RELAX, TTOLER, QTOLER, PUNCH);
```

where:

#ITERS is the maximum number of iterations to be

allowed in attempting to solve the set of simultaneous equations (FIXED BIN);

RELAX is a constant factor which is used in the correction term of an alternate solution scheme, described later in this appendix (the argument is unused in the present version of STEADY) (FLOAT BIN);

QTOLER, TTOLER are the convergence criteria for the net heat flow (Btu/h) and temperatures (°R) (i.e., the steady state is achieved if

$$|Ti - Ti'| \le TTOLER \text{ and}$$

$$|Qi| \le QTOLER,$$

with Ti - Ti' being the difference in temperature of node i between iterations and Qi being the net heat flow to node i); these criteria must be satisfied for each node in the network; and

PUNCH is a code for having the values of temperature saved on an output file named SAVE. If PUNCH is not equal to 1, the temperatures will not be saved; if PUNCH is equal to 1 then the temperatures will be written on the file SAVE in the following format:

```
LASCAP = N;

T (1) = xxxxx

  .   .   .

  .   .   .

T (N) = xxxxx;
```

In order to have the temperatures saved, PUNCH must equal 1 and a JCL card of the following type must be included at execution time:

```
//SAVE      DD  DSN=group.userid.dsname,
//              DISP=(NEW,CATLG),
//              DCB=(RECFM=FB,LRECL=80,BLKSIZE=800),
//              SPACE=(3200,(2,2),RLSE),
//              UNIT=SAVE
```

Note that LASCAP is the name of the program variable into which is stored the value N and "group.userid.dsname" is an arbitrary name for the data set that will contain the saved temperatures. N will be the largest node number in the network and will be equal to the #CAPS argument to subroutine STORE (c.f. Appendix H).

In the linkage-editing step of the job being run, the following input must be supplied:

```
//L.SYSLIB  DD  DSN=BBE.FRAZER,BASIC02,DISP=SHR
//L.SYSIN   DD  *
     INCLUDE SYSLIB (STEADYM)
     INCLUDE SYSLIB(COMCONM)
     INCLUDE(CAPCONM)
/*
```

If direct calls to subroutine RAD, CON, FORCER, or FLUX are made in the main program then the following INCLUDE cards must also be used after the "//L.SYSIN DD *" card above.

```
     INCLUDE SYSLIB(RADM)
     INCLUDE SYSLIB(CONM)
     INCLUDE SYSLIB(FORCERM)
     INCLUDE SYSLIB(FLUXM)
```

Note that no subroutine names need to be changed in any of the user-supplied code that was or could be used for a transient analysis. It is important, however, to include the required input cards to the link-editor at job assembly so the proper subroutine modules are used.

The order in which subroutines are called within the SHTP main program loop is important to the steady state analysis. In particular the routines FORCER, FLUX or SAERO must be called after all calls to CON, COMCON, or CAPCON and before the call to STEADY. If this simple convention is followed, correct results will be obtained.

The STEADY routine prints a message indicating convergence, when such is the case, or nonconvergence if the criteria for convergence are not met in #ITERS attempts. Refer to Appendix E for a description of this message.

During the early development of the steady-state routines another solution technique was employed and later found inferior in terms of machine time usage and accuracy to the one described above. This earlier technique used a Newton-Raphson iteration scheme for arriving at the steady state field.

The Newton-Raphson solution technique can be utilized in exactly the same way as described above for the Gaussian elimination technique with the following changes:

1. The TYPRUN argument to routine STORE should be set to a value of 2;

2. The following input should be provided to the link-editor in place of that shown earlier:

```
//L.SYSLIB  DD  DSN=BBE.FRAZER,BASIC02,DISP=SHR
//L.SYSIN  DD *
     INCLUDE SYSLIB (STEADYS)
     INCLUDE SYSLIB (COMCONS)
     INCLUDE SYSLIB (CAPCONS)
/*
```

If direct calls are made in the main program to the subroutines RAD or CON then the following cards should also be included after the "//L.SYSIN DD *" card:

```
     INCLUDE SYSLIB (RADS)
     INCLUDE SYSLIB (CONS)
```

3. A value needs to be assigned to the argument RELAX in the CALL statement to STEADY. This value is used to modify the successive corrections to the nodal temperatures and is normally 1. Refer to "Steady-State Temperature Fields" (Section 2 of Volume 1) for a complete description of the relaxation factor.

No other changes are required and the output messages generated are the same as previously mentioned.

Appendix O

GENERATING LIMITS PLOTS

FROM PREVIOUSLY STORED DATA

During an URLIM run the pertinent radome limitations data are saved automatically on the peripheral storage device specified by a data definition (DD) card for the file LIMPLT. These data embody all of the velocity limits data that were determined during the URLIM run and can be accessed for display. The following will show how a PL/I program can be written to read the data stored on the LIMPLT file and generate the appropriate limits plots. The data stored on the file LIMPLT were put there by a call to routine LIMIT whose usage is discussed in Appendix L.

The data that are required to produce a velocity limits plot include the trajectory (velocity versus time), maximum material capabilities, and the appropriate failure times. All of these data along with appropriate control values are read by the program shown below from the LIMPLT file. The program's main function is to re-establish the proper order of storage for the data within addressable memory and then invoke the routine that creates the limits plot, namely LIMPRNT. The significant points to notice about the program shown below and the use of subroutine LIMPRNT are as follows:

1. For each limit plot called for (#CALLS) there will be a limits structure (LIMSTR) allocated and read in from the LIMPLT file;

2. The external POINTER variables LIMPNT and TMPNTR must have the addresses of the limits structure and the trajectory data properly assigned; and

3. The largest values of time and velocity from the trajectory tables (MAXTIME and MAXV) must be calculated and provided to the LIMPRNT routine.

```
PL/I CHECKOUT COMPILER  /* VELPLOT: SETS UP AND READS DATA FROM SAVED FILE FOR OFF-LINE LIMIT*/

                    SOURCE LISTING

 STMT LEV NT

                 |/* VELPLOT: SETS UP AND READS DATA FROM SAVED FILE FOR OFF-LINE LIMIT*/|
   1         0   |VELPLOT:  PROC OPTIONS(MAIN)  RECRDER;                                   |
   2     1   0   | DCL LIMPLT  FILE RECORD INPUT;    /* File description for saved data*/ |
   3     1   0   | DCL ( TIM (*),  VEL(*),           /* Trajectory data tables         */ |
                 |       MAXV(*), MAXTIME(*) )       /* Highest vel and largest time   */ |
                 |     FLOAT BIN CONTROLLED;                                               |
   4     1   0   | DCL TMPNTR(*,*) EXT CTL POINTER; /* Address of trajectory data      */ |
   5     1   0   | DCL  LIMPNT(*) EXT CTL POINTER;  /* Address of limit data structure*/ |
   6     1   0   | DCL N FIXED BIN(31);              /* Counters, indexes, etc.        */ |
   7     1   0   | DCL DIMEN  FIXED BIN;                                                   |
   8     1   0   | DCL (#CALLS, I, J, K,                                                   |
                 |      TIMEID(*) CTL)                                                     |
                 |  FIXED BIN;                                                             |
   9     1   0   | DCL 1 LIMSTR  BASED(LIMP),      /* STRUCTURE FOR LIMIT CASE ID      */ |
                 |        2 #TRAJ FIXED BIN(31),   /* # OF TRAJS FOR LIMIT CASE ID     */ |
                 |       (2 LCDTIM(N REFER(#TRAJ)),/*TIME OF MAX BASE STRESS           */ |
                 |        2 LODLIM,                /* VALUE OF MAX BASE STRESS         */ |
                 |        2 TSTIM(N REFER(#TRAJ)),/* TIME OF MAX THERMAL STRESS        */ |
                 |        2 TSLIM,                 /* VALUE OF MAX THERMAL STRESS      */ |
                 |         2 BSETIM(N REFER(#TRAJ)),/* TIME OF BORESIGHT ERROR LIMIT     */|
                 |         2 BSELIM,                /* VALUE OF MAX. BORESIGHT ERROR     */|
                 |         2 MLTTIM(N REFER(#TRAJ)),/*TIME OF MELT FOR ANY OF MLTNODS    */|
                 |         2 MLTLIM ) FLOAT BIN,   /* MELT TEMP FOR THIS CASE           */|
                 |         2 TITLE CHAR(80),  /* TITLE CARD FOR PLOTS                    */|
                 |         2 DUNLAST(N REFER(#TRAJ)) BIT(1);                               |
  10     1   0   |  DCL LIMPRNT  ENTRY ((*)FLOAT BIN, (*)FLOAT BIN, (*)FIXED BIN,         |
                 |                         FIXED BIN);                                     |
  11     1   0   | ON ENDFILE(LIMPLT)  PUT SKIP LIST( #CALLS, N, DIMEN, TIME, VEL,        |
                 |                         LIMSTR);                                        |
  12     1   0   | N=5;                                                                    |
  13     1   0   | ALLOCATE  TMPNTR (N,6), TIMEID(N);                                      |
  14     1   0   | READ FILE (LIMPLT)  INTO (#CALLS);                                      |
  15     1   0   | ALLOCATE LIMPNT(#CALLS);                                                |
  16     1   0   | DO I=1 TO #CALLS;                                                       |
  17     1   1   |         READ FILE(LIMPLT) INTO (N);                                     |
  18     1   1   |         ALLOCATE LIMSTR, MAXV(N), MAXTIME(N);                           |
  19     1   1   |         MAXV, MAXTIME = 0;                                              |
  20     1   1   |         LIMPNT(I) = LIMP;                                               |
  21     1   1   |         DO J=1 TO #TRAJ;                                                |
  22     1   2   |                 TIMEID(J) = J;                                          |
  23     1   2   |                 READ FILE(LIMPLT) INTO (DIMEN);                         |
  24     1   2   |                 ALLOCATE TIM(DIMEN+1)  ,  VEL(DIMEN);                   |
  25     1   2   |                 READ FILE(LIMPLT) INTO (TIM);                           |
  26     1   2   |                 READ FILE(LIMPLT) INTO (VEL);                           |
  27     1   2   |             DO K=1 TO DIMEN;                 /* Calculate traj maxima */ |
  28     1   3   |                     MAXV(I)  = MAX(MAXV(I), VEL(K));                    |
```

```
PL/I CHECKOUT COMPILER  /* VELPLOT: SETS UP AND READS DATA FROM SAVED FILE FOR OFF-LINE LIMIT*/

   STMT LEV NT

    29   1  3  |            MAXTIME(I) = MAX( MAXTIME(I),TIM (K+1));                          |
    30   1  3  |         END;                                                                 |
    31   1  2  |           TMPNTR(J,1) = ADDR(TIM );                 /* Set addresses     */  |
    32   1  2  |           TMPNTR(J,3) = ADDR(VEL);                                           |
    33   1  2  |      END;                                                                    |
    34   1  1  |      READ FILE(LIMPLT) INTO (LIMSTR);               /* Get limit data    */  |
    35   1  1  |      CALL LIMPRNT( MAXV, MAXTIME, TIMEID, I);/* Call routine to   */          |
    36   1  1  |   END;                                              /* print plots.      */  |
    37   1  0  | END VELPLOT;                                                                 |
```

Appendix P

OBTAINING CALCCMP PLOTS

FROM PREVIOUSLY STORED DATA

The PLOTTER routine (described in Appendix L) can be used to generate time history plots of program data (temperatures, stresses, etc.) either at the time of the heat transfer run or later by using the data as stored on a peripheral device. The following short program shows how the data may be read from the appropriate data files and the plots made subsequent to an SHTP run. The program shown simply provides a means for conveniently reading in the desired control values and calling the plotting routine, PLOTEM. The variables are the same as defined in Appendix L. Note that the program will require:

1. Access to the load module libraries containing the routine PLOTEM and the CalComp routines PLOT, PLOTS, LINE, NUMBER, SYMBOL, and WHERE; (at APL this access is automatic via system convention)

2. The file PLOT to be defined and contain the stored temperature data;

3. A PLOTAPE file to be defined for the CalComp generated data. These items and files are discussed fully in the PLOTTER discussion in Appendix L.

```
PL/I CHECKOUT COMPILER  /* PLOTRUN - SETS UP PLOTEM ROUTINE FOR OFF-LINE CAL COMPS          */

                    SOURCE LISTING

   STMT LEV NT

                  |/* PLOTRUN - SETS UP PLOTEM ROUTINE FOR OFF-LINE CAL COMPS          */ |
    1         0   |PLOTRUN:  PROC OPTIONS (MAIN)  REORDER;                                   |
    2     1   0   |DCL    PLOTEM  ENTRY    (CHAR(*) VAR, (*,*)FIXED BIN, (*)FLOAT BIN,      |
                  |                  FLOAT BIN, (*)FLOAT BIN, FLOAT BIN, FIXED BIN);        |
    3     1   0   |DCL    FORMAT (*,*)  FIXED BIN  CTL; /* MATRIX FOR DETERMINING          */|
                  |                                     /* WHICH GROUP OF NODES  GO ON     */|
                  |                                     /* WHICH PLOT                      */|
    4     1   0   |DCL  NPTS  FIXED BIN;                /* # OF TIME POINTS ON FILE        */|
    5     1   0   |DCL   ( #PLOTS  INIT(1),             /* # OF SEPERATE PLOTS TO BE MADE*/|
                  |        PLTS_PG  INIT(8) ) FIXED BIN;/* MAX # ENTRIES TO FORMAT         */|
    6     1   0   |DCL LIST FIXED BIN INIT(0);  /* FLAG FOR READING IN FORMAT VIA      */ |
                  |                             /* LIST OR EDIT DIRECTED I/O           */ |
    7     1   0   |DCL  ( TIMSCAL INIT(2),          /* TIME UNITS PER INCH OF PLOT     */ |
                  |       TIMINIT INIT(0) )   FLOAT BIN; /* TIME VALUE AT ORIGIN       */ |
    8     1   0   |DCL   ( TMPSCAL(*),  TMPINIT(*) ) FLOAT BIN CTL; /* UNITS/INCH Y AXIS */|
    9     1   0   |ON ERROR SNAP SYSTEM;          /* SYSTEM DIAGNOSTICS WHEN ERROR OCCURS*/|
   10     1   0   |GET FILE(SYSIN)  COPY(SYSPRINT)  DATA; /* GET STARTING PARAMETERS       */|
   11     1   0   |ALLOCATE  FORMAT(#PLOTS, PLTS_PG),  TMPSCAL(#PLOTS),                      |
                  |          TMPINIT(#PLOTS);                                                |
   12     1   0   |GET FILE(SYSIN)  COPY(SYSPRINT)  DATA; /* FORMAT INPUT WITH DATA- OR */|
   13     1   0   |IF LIST = 1 THEN GET LIST( FORMAT);     /*  LIST-DIRECTED I/O         */|
   14     1   0   |CALL PLOTEM ('PLOT', FORMAT, TMPSCAL, TIMSCAL, TMPINIT, TIMINIT,         |
                  |             NPTS);                                                       |
   15     1   0   |END PLOTRUN;                                                              |


//      EXEC  PGM=PLOTRUN,
//            REGION=150K,
//            PARM='ISASIZE(15K),R',
//            TIME=(0,30)
//STEPLIB  DD  DSN=BBE.FRAZER.PLTMAKR1,DISP=SHR
//SYSPRINT  DD  SYSOUT=A,
//          DCB=(RECFM=VBA,LRECL=137,BLKSIZE=3155)
//PLIDUMP  DD  SYSOUT=A
//SYSIN  DD  *
   #PLOTS = 2   PLTS_PG  = 7    LIST = 1; <---------- SETTING PARAMETERS
   TIMSCAL =  5  TIMINIT = 0
   TMPSCAL(1) = -0.16666     TMPSCAL(2)  = 0.019 <--- NEGATIVE VALUE (KEYS SCALE FACTORS BELOW)
   NPTS = 31
   ;
    81  83  85  87  89  91  -999  }
   105  109  113  117  121  125  -999 } <----------- FORMAT VALUES
   10000   4000   22500   18400   12000   20000    0 <---- SCALE FACTORS
   'NORMALIZED STRESSES  SAM-D TRAJ'  }
   'PERCENT OF DESIGN STRESS'         }
   'BORESIGHT ERROR FOR SAM-D TRAJ'   } <---- REPLACEMENT HEADINGS
   'BORESIGHT ERROR - DEG/DEG'        }
//FT36F001 DD DUMMY,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=140)
//PLOTAP3  DD  UNIT=(TAPE9,,DEFER),VOL=SER=PLOTQ,LABEL=(,BLP),
//          DCB=(RECFM=F,LRECL=480,DEN=3)
//PLOT  DD  DSN=BBE.FRAZER.SH21514,DISP=SHR
```

The program just listed was executed with the cards shown next to generate the plot shown in Fig L-2. Close observation will show the use of the formal grid format, normalization of plots, and title changing (c.f. Appendix L, PLOTTER and PLCTEM).

Appendix Q

External Variables

Throughout the SHTP, communication of calculated data between subroutines is accomplished via the class of variable known as EXTERNAL. Since external variables must have unique names the following table is provided to show the external variable names now in use. The data type FLOAT means float binary, single precision, FIXED means fixed binary and is for integers. Asterisks for the extent of an array indicate that the variable is controlled, and has its storage dynamically allocated. Also when variable names occur as the extent of an array, the variable is controlled and the extent is the value of that variable. Further, these variables are as defined in Table 1 of this report.

Variable Name and Dimension	Data Type	Value or Use
ALPHA(#ALPHA)	FLOAT	Angle of attack (deg)
AERSIG(CALLLOD,2)	FLOAT	Aerodynamic load stresses (psi)
BSER(CALLBSE)	FLOAT	Boresight error slope
CI#	FIXED	number of capacitor with smallest allowable time step
CALPHA(2,5)	FLOAT	array of coefficients used in heat transfer correlations
CT1(*), CT2(*)	FLOAT	lists of contact temperatures in composite conductances (°R)
C(#NODES)	FLOAT	heat capacity values for each node (Btu/ft³-°R)

Variable Name and Dimension	Data Type	Value or Use
CNM(#ALPHA,#MACH)	FLOAT	normal force coefficients for missile
CNR(#ALPHA,#MACH)	FLOAT	normal force coefficient of the radome
CAR(#ALPHA,#MACH)	FLOAT	axial force coefficient of the radome
DCHI(CALLBSE)	FLOAT	list of electrical thickness changes for radome walls
DLTMS	FLOAT	the time step (s)
DQ(*)	FLOAT	values of derivatives of the net heating rate of a node with respect to the node's temperature (Btu/h-°R)
ENDTIM	FLOAT	time for termination of the run (h)
FIRST	FIXED	loop counter
FILENAME	RECORD INPUT FILE	used by PLOTEM for reading in data to be plotted
FLPNTR(*,*)	POINTER	addresses of tables of local flow ratios versus Mach number
GAMMA(*,*)	FLOAT	values of specific heat ratio of air versus temperature and pressure
HAIR(*,*)	FLOAT	values of enthalpy (Btu/lbm) for air versus temperature and pressure
HMAT(#NODES,#NODES)	FLOAT	conductance matrix for steady-state solutions

Variable Name and Dimension	Data Type	Value or Use
H(#NODES)	FLOAT	thermal conductance values for each node (Btu/h-°R)
IA(*), IB(*)	FIXED	lists of nodes that are joined by composite conductances
ICOMCN	FIXED	number of composite conductances
IASEQ(*)	FIXED	list of indexes
LASCAP	FIXED	number of thermal nodes
LIMPNT(CALLLIM)	POINTER	list of addresses for LIMSTR structure
LASTIM	FLOAT	value of a previous time point (s)
MACH#(#MACH)	FLOAT	Mach number values
MAXPRNT	PRINT FILE	optional file for extended output
MINPRNT	FIXED	Flag for print option
MAXSTRS(CALLSIG)	FLOAT	Maximum tensile thermal stress (psi)
MAXBSER(THROPS)	FLOAT	maximum allowable boresight error values for thermal materials
MOR(MCPROPS)	FLOAT	Modulus of Rupture values for mechanical materials (psi)
MINRUN	FIXED	flag for limiting execution in URLIM runs
MUAIR(*,*)	FLOAT	values of viscosity for air (lbm/ft-s) versus temperature and pressure

Variable Name and Dimension	Data Type	Value or Use
PALT(*)	FLOAT	static pressure values (function of Z, lbf/ft^2)
PP(45)	POINTER	list of thermal property table addresses
PLTFILE	RECORD OUTPUT FILE	used by PLOTTER to store data for plotting
PAIR(*)	FLOAT	logarithm of pressure variable for air property values
PRAIR(*,*)	FLOAT	values of Prandtl number for air versus pressure and temperature
PRINTIT	BIT(1)	flag indicating output
Q(#NODES)	FLOAT	heating rate values for each node (Btu/h)
QE(#NODES)	FLOAT	values of net heat flows for steady-state solutions (Btu/h)
SAVSIG(CALLLOD,2)	FLOAT	aerodynamic load stresses at previous time step (psi)
SOUND(*)	FLOAT	sonic velocity (ft/s) function of Z
SYSPRINT	PRINT FILE	standard system output file
SYSIN	STREAM INPUT FILE	standard system input file
SAVBSER(CALLBSE)	FLOAT	boresight error slope at previous time step

Variable Name and Dimension	Data Type	Value or Use
SAVSTRS(CALLSIG)	FLOAT	maximum tensile thermal stress at previous time point (psi)
STOP	BIT(1)	flag for stopping execution
SAVT(#NODES)	FLOAT	nodal temperatures from previous time point (°R)
SAVE	STREAM OUTPUT FILE	output file for saving nodal temperature data from steady state solutions
T(#NODES)	FLOAT	temperature values for each node (°R)
TIMS	FLOAT	time variable (s)
TMPNTR(CALLTIM,5)	POINTER	address table for time-dependent variables
TEMPIN	FLOAT	initial temperature for all nodes at start of run (°R)
TAIR(*)	FLOAT	values of temperature for air property tables (°R)
TALT(*)	FLOAT	values of temperature versus altitude (°R)
TSPACE(*)	FLOAT	values of the space temperature versus altitude (°R)
TIM	FLOAT	current simulation time (h)
VI(*)	FLOAT	a list of nodal volumes (ft^3)
XCPL(#ALPHA,#MACH)	FLOAT	center of pressure values for radome
XCAP(XCAPLIM,7)	FLOAT	nodal interconnection matrix

Variable Name and Dimension	Data Type	Value or Use
Z(*)	FLOAT	altitude (ft)
ZAIR(*,*)	FLOAT	values of compressibility for air versus pressure and temperature

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